RESPONSE OF A SEMI-SUB PLATFORM TO ENVIRONMENTAL LOAD

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By

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FINAL PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
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(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

AP Dr Saied Saiedi
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Faiz Bin Mohd Yaacob

ABSTRACT

The increasing usage of floating platforms such as semi-submersibles in the exploration and production of oil & gas has increase the number of research on floating platforms. One of the important researches is to investigate and predict the movement of floating platforms caused by environmental loads. One of the major components in the design of a semi-submersible platform is to predict its motion response due to waves. Nowadays, engineers have computer software to do the calculation and simulation to predict the response of a floating structure. Not many would do an experiment to compare and see if there is any agreement between the computer analysis value and the experimental value. So from this research, exclusive experimental value will be achieved and a comparison can be made between computer analysis value and experimental value. Later these results can and will contribute to the designs of future semi-submersibles platform. This research will be based on real life model testing of a scaled down semi–submersible platform. The model was based on a prototype semi-submersible platform design for Malaysian waters by a group of students from a foreign university. The study targets to fill a vacuum in the design of such important structures by conducting physical modelling. Changing the wave height, wave period, and ballast conditions, a series of laboratory tests was achieved at 20 m×10 m×1.2 m wave basin of the Coastal Engineering Laboratory, Universiti Teknologi PETRONAS, under regular waves and random waves while the semi–submersible is moored by 16 mooring lines connected to the basin floor. The dynamic response of the semi–submersible was monitored by photographic methods and the heave, surge and pitch of the structure were plotted vs. time. The analysis of the maximum responses showed the significance of the wave period and ballast condition. The scale modelling data show a satisfactory similarity with the prototype. An equation of motion for heave motion was also constructed and it can be applied to predict the motion response of the semi–submersible. A force test was also conducted to get the value of force from wave and current towards the semi-submersible model. The force calibration result can later be applied to compare theoretical force calculation with experimental values.

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LIST OF ABBREVIATIONS

Nomenclatures	
MG	Metacentric height (cm)
G	Center of gravity (cm)
B	Center of buoyancy (cm)
GB	Distance from center of gravity to center of buoyancy (cm)
I	2nd Moment area (cm^4)
V_s	Volume of submerged body (cm^3)
K	Stiffness (kg/m)
M	Mass (kg)
A	Area (m^2)
T_n	Natural period (s)
L_r	Scaling ratio
h	Water depth (cm)
H	Wave height (cm)
H_s	Significant wave height (cm)
L_m	Measured wave length (cm)
L_t	Theoretical wave length (cm)
T	Wave period (s)
d	Draft (cm)
d_m	Distance from padeye to basin floor (cm)
B_o	Pontoon width (cm)
F	Force (kN)
C	Damping coefficient

Greek Symbol	
γ	Weight Density (kg/m^3)
ω_n	Natural Frequency (Hz)
ξ	Damping Factor

CHAPTER 1
INTRODUCTION

1.1 Background

Development of oil and gas exploration and production has led to the increase usage of floating offshore platforms. Floating offshore platforms includes tension leg platform (TLP), semi–submersibles, SPARs and ship shaped vessels. A semi-submersible is a floating offshore platform that consists of pontoon and columns that, if flooded with water, will cause the pontoon to submerge to a depth that is predetermined. Semi–submersible platform work on the same principle as submarines; through the 'inflating;' and 'deflating; of its hull [Sadeghi, 2007]. The semi-submersible platform will be placed at one specific position and anchored to the seabed with a number of mooring lines attached to anchors. These mooring lines are the only support that will prevent the floating structure from rotating and respond extremely due to environmental forces. The floating structure will behave and respond dependently towards various environmental forces such as wave, wind and current [Bowers et al., 1997]. The response of a floating structure is a combination of six modes of motion: three translational and three rotational. These six modes are depicted schematically in Figure 1 below.

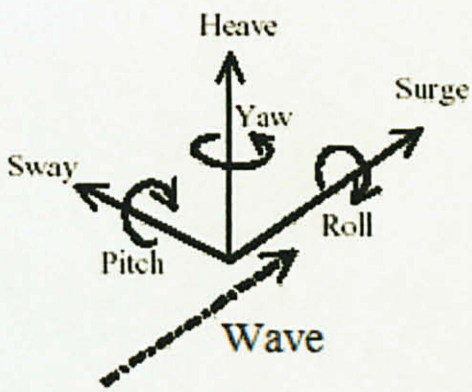

Figure 1 Semi-Submersible Motion Indicator

1.2 Problem Statement

In an open sea, a semi–submersible platform will be subjected to environmental loads especially waves. So wave action is dominant in the design and one of a major component in the design of any floating offshore platforms, especially semi-submersible, is to estimate its dynamic responses. Meaning all the response of a floater in six modes of motions must be known. This estimation could be based on extensive field data on similar structures, analytical solutions, numerical simulation (ANSYS, SACS 2005, STAAD 2005), and laboratory experiments. The first is often employed as supporting evidence to other analyses and rarely is viewed sufficient for the design. The second is often hard to achieve except for hypothetical cases with grossly simplified assumptions. With the advent of sophisticated computers and development of advanced computational methods, the third methods have gained much popularity in the last three decades as it is fairly cheap, fast and readily reproducible. Numerous computer simulations of response of semi–submersibles have been reported in the literature (Bowers et al. 1997, Söylemez 1998, Wu et al. 1997, Yilmaz and Incecik 1996). The last method provides for invaluable insights or data into the actual behaviour of the structure but requires extensive laboratory resources as well as modelling skills. Due to the complexity of the governing equations for the dynamic response of FOPs, a large variety of different structural configurations, uniqueness of loadings for any specific structure, the designer must, in most cases, resort to the experimental studies into the response of FOPs to validate computer simulations or to obtain calibrated values for a variety of empirical factors in the governing equations. Therefore, experimental investigation has become an indispensable part of the design of many FOPs.

So this research is an attempt towards experimental simulation to obtain the motion response of a semi–submersible offshore platform towards waves. As up until now, not many have performed experimental investigation in the design of a semi–submersible platform. So the result of the experimental study will contribute to the design of a semi–submersible platform and can be use to evaluate data produced by computer analysis in predicting the response of a semi–submersible platform in the design stage.

1.3 Objectives and Scope of Study

The model test conducted is:

1. To obtain exclusive experimental data for the response of a Semi-Submersible
2. To evaluate or compare existing data produced by computer analysis with the experimental data

This project focuses on:

1. Design and fabricate a scale model of a semi-submersible platform and run test using the model in the wave tank under different conditions.
2. Use video imaging technique to gather all the data from the test.
3. Compare and analyze the data with a published journal.

CHAPTER 2
LITERATURE REVIEW

2.1 Hydrostatic Stability

A floating object is stable if it tends to restore itself to an equilibrium position after a small displacement. For example, floating objects will generally have vertical stability, as if the object is pushed down slightly, this will create a greater buoyant force, which, unbalanced against the weight force will push the object back up.

Metacentric height, *MG*, is given by

$$MG = MB - GB \text{ or } MG = (I / V_s) - GB \qquad (1)$$

Where I is a 2nd moment of area of plan section of the body where it cuts the waterline. In other words, if you were to cut horizontally through the body of water surface and look at the area of the body exposed by the cut, I is the 2nd moment of area of that body about the longest axis. V_s is the submerged volume or volume of water displaced and *GB* is the distance between center of gravity and center of buoyancy. Figure 2 shows the orientation of *M*, *G* and *B*.

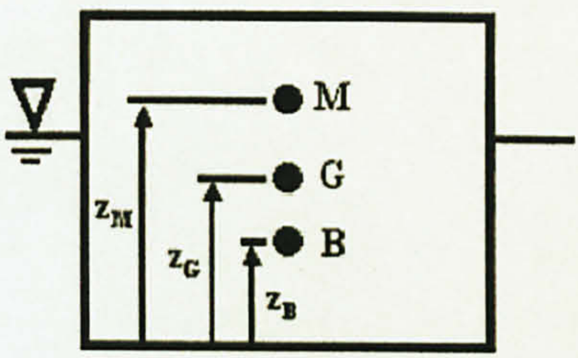

Figure 2 Orientation of M, G and B

2.2 Numerical Formulations

O. Yilmaz and A. Incecik (1995), documented, motion response of offshore structures can be predict by using time domain or frequency domain models or model tests. The frequency domain analysis uses the simplified, linearized form of the motion equations and it is very economical. The time domain analysis, unlike frequency domain models, is adequate to deal with non-linearities such as viscous damping and mooring forces, but it requires sophisticated solution techniques and it is expensive to employ. For moored semi-submersibles time domain techniques must be employed since there are strong non-linearities in the system due to mooring line stiffness and damping and viscous drag forces. Two different time domain models are developed, first one is for simulation of wave frequency motions in which the first-order wave forces are the only excitation forces, second one is to simulate the slowly varying and steady motions under the excitation of slowly varying wave, current and dynamic wind forces. At the last stage motion responses and mooring forces obtained from the two time domain simulations are combined to find the total extremes.

According to S. Wu, J. J. Murray and G. S. Virk (1996), in numerical formulation, the semi-submersible is modeled as an externally constrained floating body in waves, and the linearized equations of motions were derived. For convenience of systematically formulating the internal forces, the body was subdivided in the derivation. The hydrodynamics computations were done by using a surface panel method. The force and moment exerted by an external constraint were decomposed into a constant component and a linearized-motion-dependent component. The internal forces between two parts of the body were decomposed in the same way. The linearized equations of motion of each part were obtained in a common reference system fixed on the body. The result of the equation of motion will give the response motion and internal forces acting to the floating structure.

2.3 Floating Structure Dynamics

According to S. K. Chakrabarti text book entitled, Hydrodynamics of Offshore Structures (1987), the motion response of a floating structure can be determined from solving equations of motion in various degrees of freedom. From the motion response, the stress distribution of the structure can be determined. There are basically two approaches that can be use to solve the equations of motion – frequency domain or time domain analysis. Frequency domain analysis can solve equations of motion by simple iterative techniques. It has already been applied extensively and is use to predict long term responses. It can also estimate responses due to random wave input through spectral formulations. This technique is more preferable than the time domain analysis because it is simpler, but one limitation is that all nonlinearities in the equation of motion must be replaced by linear approximations. Time domain analysis is a direct numerical integration of equations of motion and it includes all nonlinearities. One disadvantage of time domain is that it is more difficult to interpret and apply because of the increased computer time and increased complexity in the computed results. No matter which solution technique was used, the equations of motion will still be the same.

CHAPTER 3
METHODOLOGY / PROJECT WORK

This section explains the methods or procedure taken for the project. Figure 3 below would be the flow chart of the whole project that has been planned.

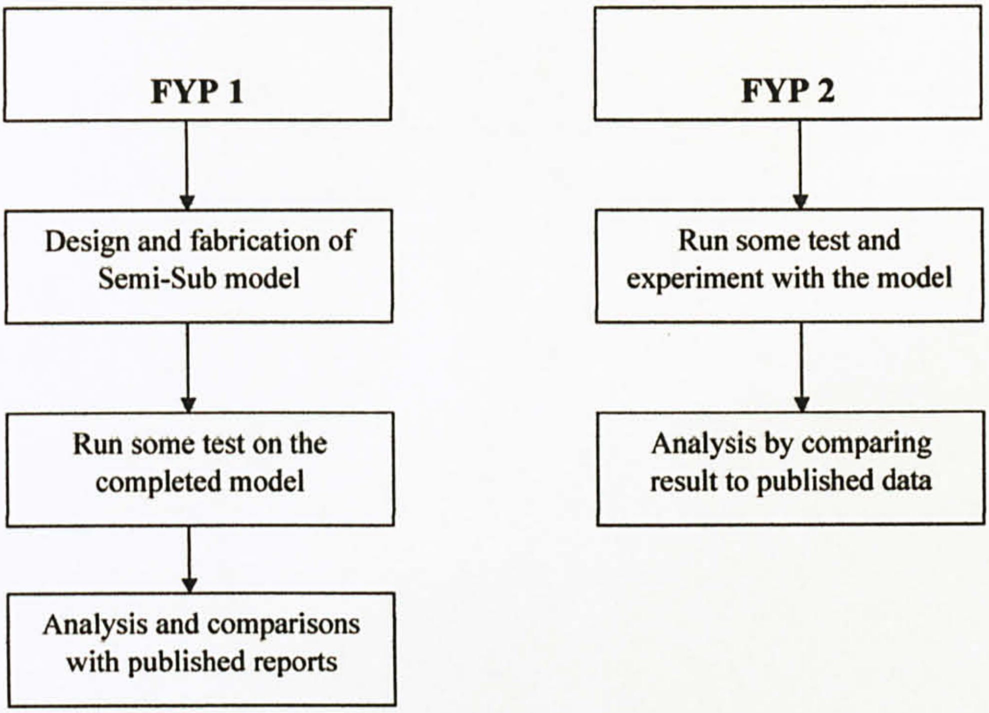

Figure 3 Project Flow Chart

3.1 Semi - Submersible Scale Model

The Semi–Submersible of the case study, is a prototype semi–submersible platform designed by a group of students from a foreign university. They produced a report entitle "Conceptual Design of a Semi-Submersible Floating Oil and Gas Production System for Offshore Malaysia". The semi–submersible is equipped with one hollow square pontoon and four square columns. Figure 4 and 5 shows the location map and graphic views of the structure and its components.

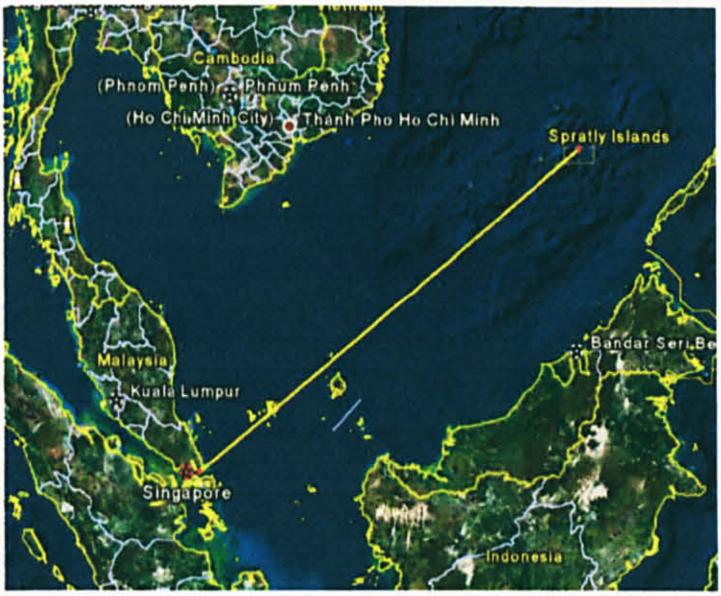

Figure 4 Location Map

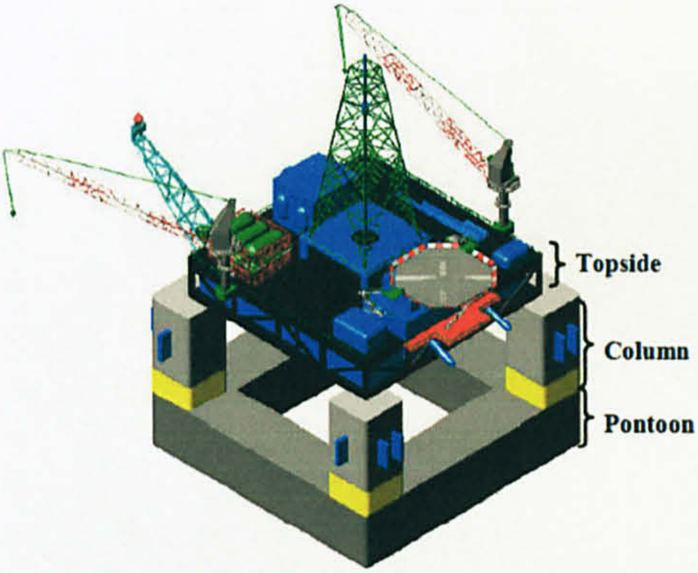

Figure 5 Prototype

The prototype was proposed for a water depth of 5500ft in South China Sea off the coast of Malaysia. There were three drafts given; 5.91m for loadout, 26m for operating condition and 20.4m for survival condition. Statistical analysis of the waves in the region led to the design wave of 10 m height and 12.7 sec period with a return period of 10 years and a design wave height of 12m height and 13.1 sec period with a return period of 100 years. The design studies based on computer simulations have suggested a maximum of +/- 5m heave for both 10 and 100 years return period. For pitch, maximum +/- 4° pitch for return period of 10 years and +/- 10° pitch for return period of 100 years storm conditions [Bea et al.].

The semi-submersible model has been design according to figure and specifications of the prototype in the report. Due to the limitation of water depth in the wave tank, scale of 1:100 was used to scale down the dimension and weight of every component of the prototype semi-submersible platform. Froude scaling laws was applied and it will be discussed in the later part of the report. The weights were scaled down so that the model will have the same weight distribution as the prototype. A correct weight distribution will get the model to float at the correct draft. One way to get a correct weight distribution is by choosing the right thickness for each plate use to fabricate the model. All the calculation spreadsheets in designing the model will be included in the Appendix. The dimensions of the prototype and model are given in Table 1 below.

Table 1 Prototype and Model Dimensions

Description	**Prototype**	**Scale Model**
Pontoon Width (Outer)	83 m	0.83 m
Pontoon Width (Inner)	53 m	0.53 m
Pontoon Height	13 m	0.13 m
Column Width	15.2 m	0.15 m
Column Height	24.4 m	0.24 m
Topside Width	65 m	0.65 m
Topside Height	11 m	0.11 m
Weight of Pontoon	302986 kN	30.9 kg
Weight of Columns	52044 kN	5.31 kg
Weight of Topside	179068 kN	18.3 kg
Weight of whole model	553532 kN	54.6 kg

The whole weight of the structure will be approximately 54 kilograms (Kg) and the whole height will be 0.49 meter. The design of the model will follow the operating condition draft of the prototype, so the scaled down draft is 26 cm. The model has 16 padeyes for 16 mooring lines with three different arrangements, in total there will be 48 padeyes. The columns of the model can be detachable so that a different size or shape of column can be use for model testing in the future. The hull is scaled at the column and pontoon with visible measuring tapes. The topside is made out of wood and it was taken from a previous similar semi–submersible model that was used by a senior student. A color mark denoting draft is highlighted at all four columns and a mark at one face of the pontoon will allow visual tracing of the semi–submersible model. Figure 6 and 7 shows the AutoCad drawing and the scaled model in which various labels are used to show various components and draft under full ballast.

Figure 7 also shows the material used to fabricate the model. The bottom part of the model was made of Perspex and the topside was made of wood. One problem faced during the fabrication is that, the pontoon and column did not achieve the needed weight because the contractor could not fabricate it according the thickness calculated. So steel plates and rubber mat with the right thickness was added in the pontoon and column to make sure it will achieve the correct weight and distributed evenly.

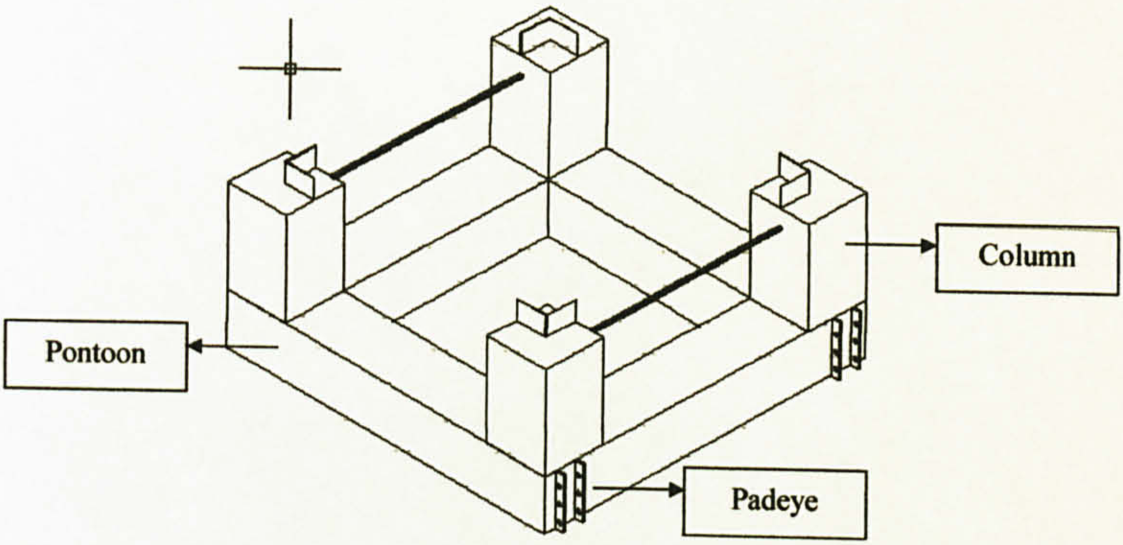

Figure 6 AutoCad Drawing of Semi-Submersible Model

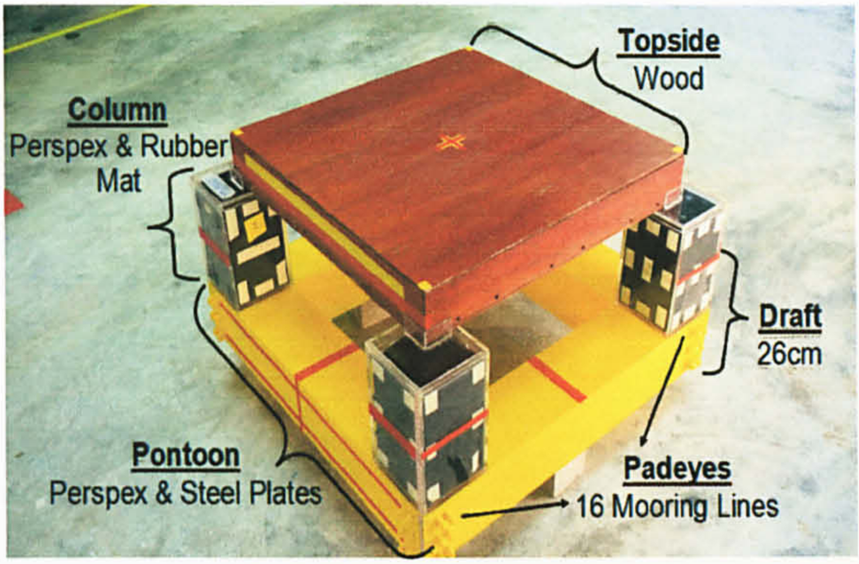

Figure 7 Semi-Submersible Model

One of the important properties of any floating offshore structure is its natural frequency, ω_n, as determined by

$$\omega_n = \frac{2\pi}{T_n} = \sqrt{\frac{K}{M}} = \sqrt{\frac{\gamma \times A}{M}} \tag{2}$$

Where,

T_n is the natural period,

K (stiffness) = $\gamma \times A$,

M (mass),

- M (full ballast) = 54.6 kg,
- M (minimum ballast) = 37 kg,

γ (weight density of seawater) = 10000 kg/m^3,

A is the cross-sectional area of the submerged section of the structure,

- $A1 = 0.15 \times 0.15 \times 4 = 0.09$ m^2,
- $A2 = (0.83 \times 0.83) - (0.53 \times 0.53) = 0.408$ m^2,

$$K1 = \gamma \times A1 = 10000 \times 0.09 = 900 \text{ kg/m} \quad (3)$$

$$M1 = 900 \times 54.6 = 49140 \text{ kg}^2\text{/m}$$

$$\omega_n 1 = 0.135, \text{ thus } T_n 1 = 46.5 \text{ sec} \quad (4)$$

$$K2 = \gamma \times A2 = 10000 \times 0.408 = 4080 \text{ kg/m} \quad (5)$$

$$M2 = 4080 \times 37 = 150960 \text{ kg}^2\text{/m}$$

$$\omega_n 2 = 0.164, \text{ thus } T_n 2 = 38.3 \text{ sec} \quad (6)$$

The model is complete and ready for testing. Below Figure 8 and 9 shows the model and mooring lines as installed in the basin during model testing. More pictures of the model will be included in Figure A in the Appendix.

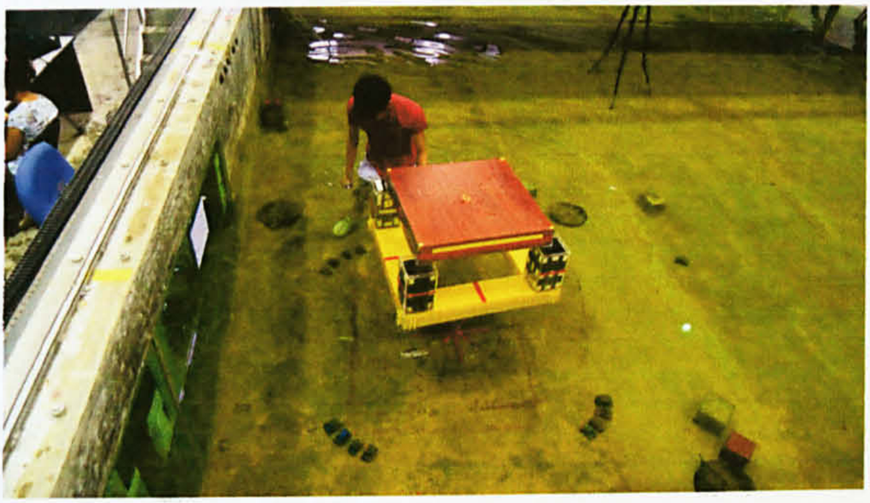

Figure 8 Arrangements of Anchors

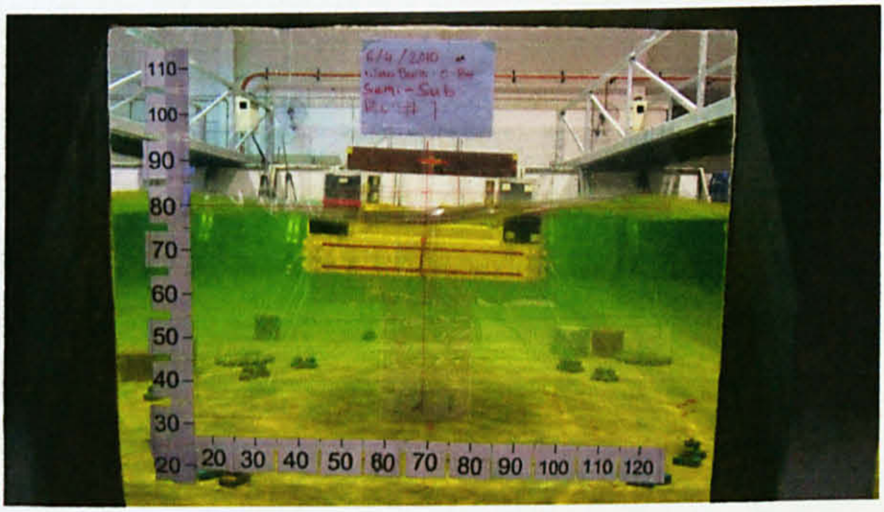

Figure 9 Model Setup in Wave Basin

3.1.1 Scaling Rule

Knowing the dynamic motion of the structure is dominated by gravity and kinematic forces, Froude scaling laws were employed for relating the model to the prototype. These scaling ratios for most important quantities are given in Table 2. With the geometric scale chosen (1:100) and ratios given in Table 2, prototype wave period is 10 times the model wave period. For example, a wave period of 0.8 sec in the wave basin corresponds with an ocean wave of 8 sec period.

Table 2 Froude Scaling Law

Physical Parameters	Unit	Scaling Ratio
Length	[m]	$L_r = 1/100$
Structural Mass	[kg]	$L_r^3 = (1/100)^3$
Force	[N]	$L_r^3 = (1/100)^3$
Moment	[Nm]	$L_r^4 = (1/100)^4$
Acceleration	[m/s²]	1
Time	[s]	$L_r^{1/2} = (1/100)^{1/2}$
Pressure	[Pa=N/m²]	$L_r = 1/100$

3.2 Hydrostatic Stability

The hydrostatic stability test was done to show the stability of the semi-submersible model in water. The stability of the structure can be proven by using the equation (1) shown in Chapter 2 before. With the changes in weight, the hydrostatic stability of the model needs to be calculated. This is to make sure the model will be able to float stable.

Below are the procedures to calculate the hydrostatic stability:

1. From geometry of body and density of fluid and body equate; Weight of displaced fluid = Total weight of body. This gives the depth of immersion of the body or the weight of the body, whichever is unknown.
2. To assess stability, first find the location of the centre of gravity, *G* of the body.

3. Then, find the location of the centre of buoyancy (centroid of displaced volume). For a regularly shaped body this will be at half the height of the immersed portion of the body (draft).
4. Calculate distance *GB*.
5. Calculate *MB*, using $MB = I / V_s$, where I is the moment of inertia and V_s is the volume of water displaced.
6. Calculate metacentric height, *MG* from $MG = MB - GB$. If $MG > 0$ then body is stable. If $MG < 0$ then body is unstable.

From this calculation, the floating stability of the structure can be investigated with the change of weight on each structure component. All of the calculations will be included in the Appendix and the results will be presented in the next chapter.

3.3 Model Testing

As stated earlier, this research is based on experimental testing of the semi–submersible scaled model towards wave. So a series of test will be conducted to see the motion response of the semi–submersible model towards wave in the wave basin. All wave tests will have different wave conditions. It is to see how the semi–submersible model response and an actual data of its response can be achieved.

3.3.1 Wave Basin

All model testing were performed in the wave basin at the Coastal Engineering Laboratory of Civil Engineering Depart of Universiti Teknologi PETRONAS. Figure 10 below gives a view of the basin. The basin is 20m long, 10m wide and 1.20m deep. It is equipped with multiple paddle wave maker of piston type capable of generating regular, irregular and directional waves. There are numbers of wide glass views at both sides of the basin to allow visual and photographic record of the tests.

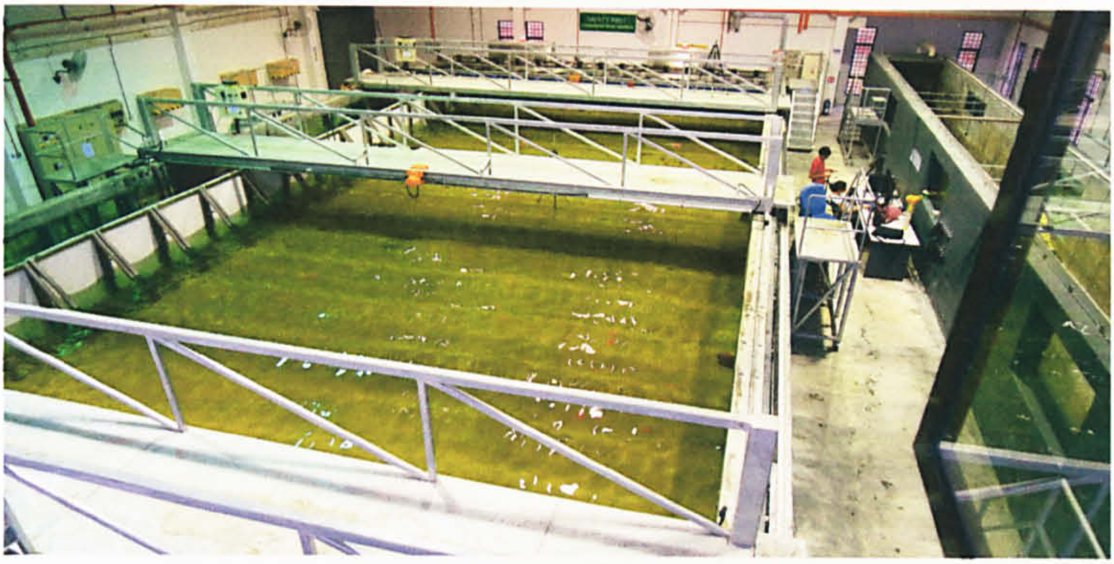

Figure 10 Wave Basin

3.3.2 Experimental Setup

All model testing will be conducted in wave basin and the model will be setup in the basin. The semi–submersible model will be connected by mooring lines (made of 100 pounds fishing lines) to sixteen anchors which are placed at the basin floor. Positions of each anchor have been marked initially by markers at the basin floor. The layout position of the joint and the angle of each mooring line with the model resemble those of the prototype. Transparent grids will be stick onto the glass view window and the water line will be marked on the grid. Three synchronized video cameras, one from the top and another two from the glass view, will record the motions of the model due to wave. The first camera (camera C) was to capture any sway motion (motion towards Z-direction) from the top of the model. Two cameras at the side glass view mirrors are to capture surge, heave and pitch motions (camera A) and wave fluctuations (camera B). Video from camera A will later be analyzed to extract the data needed to compute surge, heave and pitch. Simple geometric and trigonometric rules were applied to correct for the fact that the two – dimensional view on the glass is not mistaken for the actual movement of the structure that is located at a distance the other side of the mirror. Wave characteristics such as, wave height, wave period and wave length can be obtained from analyzing video of camera B. The wave fluctuations plotted in the results are also obtained from the video. Waves are also recorded by several wave probes and the data were double checked with the actual fluctuations from the video films. All video films were displayed in slow motion to allow accurate record of the movements and times to 1/100th of a second. Figure 11 shows the positions of all three cameras.

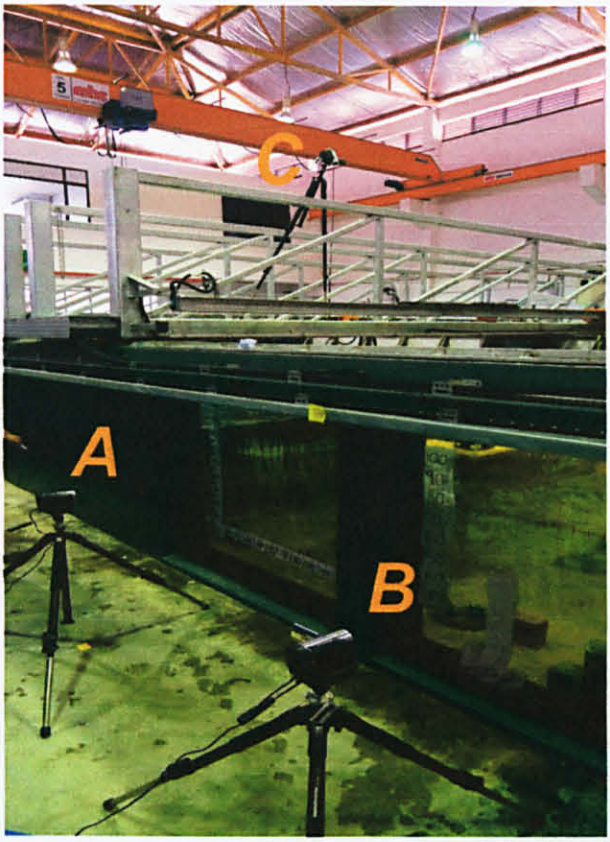

Figure 11   Position of Cameras A, B and C

3.3.3 Wave Test

Wave test is the main experiment of this research. Result from this experiment can show the actual movement of the semi–submersible due to wave loads in an open sea. To come up with the test plan, major design parameters were varied systematically to cover a range as wide as possible.

The changing parameters include:

a. Wave height, H

b. Wave Period, T

c. Loading condition (full or minimum ballast)

d. Mooring positions

e. Wave type (regular or random wave)

Estimated there will be around 31 wave tests with changing parameters to be done. With the changing parameters, the significance of each parameter can be seen in the motion response of the semi–submersible later. Table 3 shows the configuration of all 31 tests. From the configurations it can be seen that the wave periods are far from the natural period of the structure given in Equation (4) and (6). This makes the structure safe against any possibility of resonance. Figure 12 below shows the model configuration, tied down by mooring line to anchors on the floor of the wave basin. It also shows the meaning for some symbols used in Table 3.

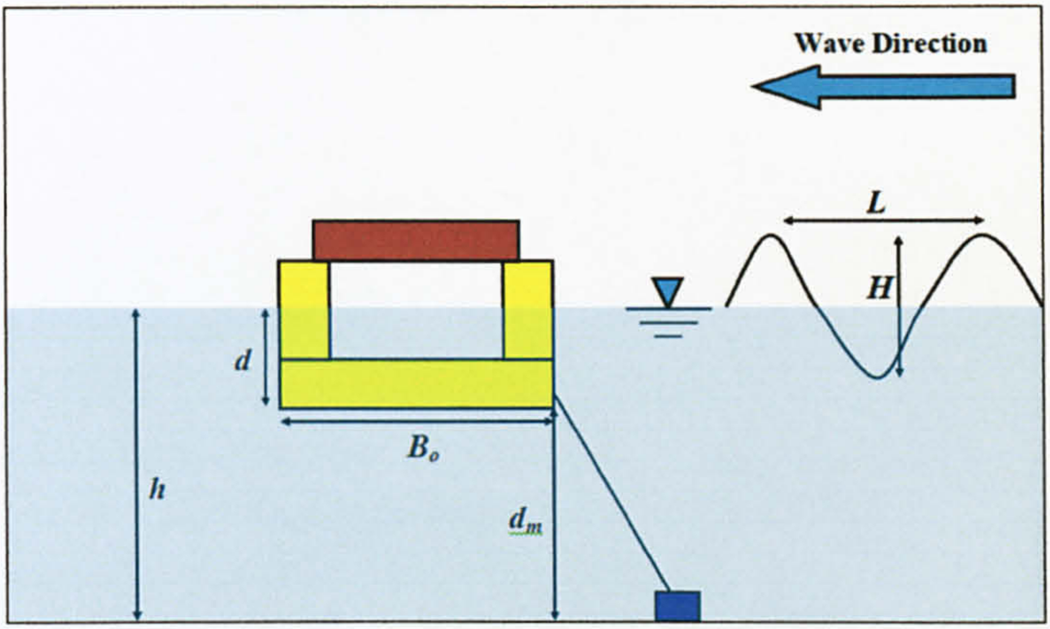

Figure 12 Illustration of Model Configuration

Table 3 List of Wave Tests

	Water	Structure			Wave						Non-Dimensional Parameter			
	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14
Test No.	h (cm)	M (kg)	d (cm)	d_m (cm)	Type	H (cm)	H_s (cm)	T (s)	L_m (cm)	L_t (cm)	$H/(gT^2)$	$d/(gT^2)$	H/L_m	B_o/L_m
1	80	54.6	26	56	Regular	3	3.0	0.8	127	100	0.005	0.041	2.36	0.654
2	80	54.6	26	56	Regular	5	4.5	0.8	127	100	0.008	0.041	3.94	0.654
3	80	54.6	26	56	Regular	7	7.5	0.8	127	100	0.011	0.041	5.51	0.654
4	80	54.6	26	56	Regular	10	9.0	0.8	127	100	0.016	0.041	7.87	0.654
5	80	54.6	26	56	Regular	12	11.5	0.8	127	100	0.019	0.041	9.45	0.654
6	80	54.6	26	56	Regular	15	13.5	0.8	127	100	0.024	0.041	11.81	0.654
7	80	54.6	26	64	Regular	3	3.0	0.8	127	100	0.005	0.041	2.36	0.654
8	80	54.6	26	64	Regular	5	4.5	0.8	127	100	0.008	0.041	3.94	0.654
9	80	54.6	26	64	Regular	7	7.5	0.8	127	100	0.011	0.041	5.51	0.654
10	80	54.6	26	64	Regular	10	10.0	0.8	127	100	0.016	0.041	7.87	0.654
11	80	54.6	26	64	Regular	12	11.5	0.8	127	100	0.019	0.041	9.45	0.654
12	80	54.6	26	64	Regular	15	13.5	0.8	127	100	0.024	0.041	11.81	0.654
13	80	36.6	13	70	Regular	3	3.0	0.8	127	100	0.005	0.010	2.36	0.654
14	80	36.6	13	70	Regular	5	4.5	0.8	127	100	0.008	0.010	3.94	0.654
15	80	36.6	13	70	Regular	7	7.5	0.8	127	100	0.011	0.010	5.51	0.654
16	80	36.6	13	70	Regular	10	8.5	0.8	127	100	0.016	0.010	7.87	0.654
17	80	36.6	13	70	Regular	12	11.5	0.8	127	100	0.019	0.010	9.45	0.654
18	80	36.6	13	70	Regular	15	13.5	0.8	127	100	0.024	0.010	11.81	0.654
19	80	36.6	13	80	Regular	3	3.0	0.8	127	100	0.005	0.010	2.36	0.654
20	80	36.6	13	80	Regular	5	4.5	0.8	127	100	0.008	0.010	3.94	0.654
21	80	36.6	13	80	Regular	7	7.5	0.8	127	100	0.011	0.010	5.51	0.654

	Water	Structure			Wave						Non-Dimensional Parameter			
	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14
Test No.	h (cm)	M (kg)	d (cm)	d_m (cm)	Type	H (cm)	H_s (cm)	T (s)	L_m (cm)	L_t (cm)	$H/(gT^2)$	$d/(gT^2)$	H/L_m	B_o/L_m
22	80	36.6	13	80	Regular	10	8.5	0.8	127	100	0.016	0.010	7.87	0.654
23	80	36.6	13	80	Regular	12	11.5	0.8	127	100	0.019	0.010	9.45	0.654
24	80	36.6	13	80	Regular	15	13.5	0.8	127	100	0.024	0.010	11.81	0.654
25	80	54.6	26	56	Regular	7	7.5	1.25	237	237	0.005	0.017	2.95	0.350
26	80	54.6	26	56	Regular	10	9.5	1.25	237	237	0.007	0.017	4.22	0.350
27	80	54.6	26	56	Random	3	-	-	-	-	-	-	-	-
28	80	54.6	26	56	Random	5	-	-	-	-	-	-	-	-
29	80	54.6	26	56	Random	7	-	-	-	-	-	-	-	-
30	80	54.6	26	56	Random	10	-	-	-	-	-	-	-	-
31	80	54.6	26	56	Random	12	-	-	-	-	-	-	-	-

Note:

(1) Definitions for all symbols can be found in the list of abbreviations and also shown in Figure 12.

(2) Width of pontoon, B_o = 0.83 m / 83 cm

3.4 Damping Test

The response of a floating platform can be predicted by solving equations of motion in various degrees of freedom. One of the simplest floating structure dynamics is by describing the system as a damped spring–mass system with a single degree of freedom. Figure 13 below shows is a simplified example of heave motion.

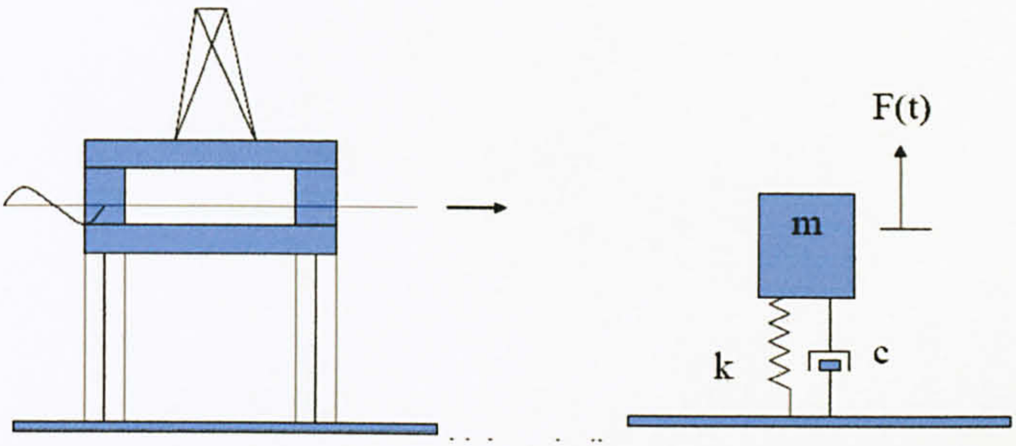

Figure 13 Simplified Heave Motion & Free Body Diagram

From the free body diagram, it shows a system with a mass, *M*, a spring constant, *K*, and it is considered linearly damped with a damping coefficient, *C* and subjected to a force, *F(t)*. So the equation of motion will consist of an inertia force, a damping force and a restoring force term all resisting the external force [Chakrabarti, 1987]. Thus it gives the equations of motion as below,

$$Mx'' + Cx' + Kx = F(t) \tag{7}$$

Due to the absence of external excitation, so it is considered as free vibration and force $F(t)$ will equal to zero, $F(t) = 0$.

Damping test was done according to configuration in figure above. The model was placed in the wave basin and not tied down by mooring lines. The semi–submersible model was displaced from its equilibrium position by pushing it down into the water and then releasing it. Camera will later record the damped oscillation of the model. By using the same concept as wave test, the video will be analyzed to extract data needed to achieve its oscillation. From the oscillation data, a graph of the oscillation is plotted and an exponential curve can be fitted to the peaks of the graph. The equation of the exponential curve can help to equate the natural frequency, ω_n and damping factor, ξ, thus finding the damping coefficient, C. In the end the EOM for heave motion can be produced.

3.5 Force Test

Surge motion of the semi–submersible will depend on wave action. Wave force will move the model in surge direction and mooring lines are the ones that will resist the motion and pull it back to its original position. So the oscillation of the model in X – direction can also be plotted as heave motion above. The model will be tested to variations of waves and current, and the wave force will be recorded using a weight scale. The model will be tied to a line that is tied to the weight scale at the other end at an angle. Motions of the model and the reading from the weight scale will be recorded from two different cameras; one to record the readings from the weight scale and the other to record the movement of the model. Waves and current velocity will be recorded by wave probes and current meter. Figure 14 and 15 below shows the weight scale used for the test and configuration of the model for force test.

Figure 14 Weight Scale

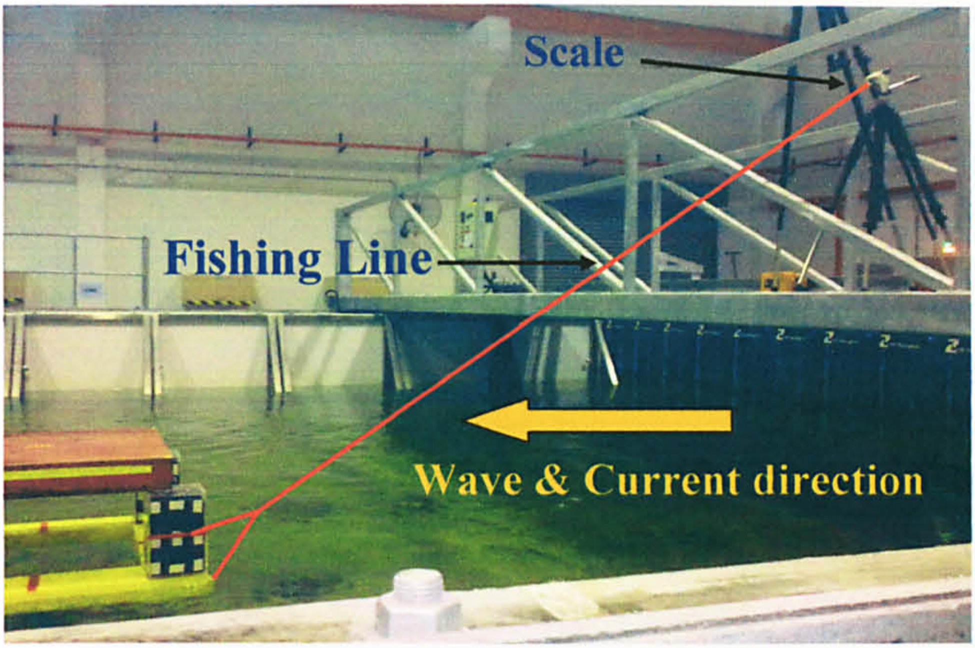

Figure 15 Model Configuration in Wave Basin

Video of the weight scale reading will later be analyzed to extract the data produced from the weight scale. Simple trigonometric rules were applied to correct for the fact that the force is measured from an angle because the fishing line was tied to a certain angle. Later the wave force reading can be plotted to a graph. Four tests with a total of 12 runs (three runs for each test) were planned with variations of waves and current. Table 4 shows the test configurations planned.

Table 4 List of Force Tests

No	Test	Wave	H (cm)	T (sec)	Current	Velocity (cm/s)
1	1	-	-	-	Yes	0.15
2		Yes	3	0.8	Yes	0.15
3		Yes	3	0.8	-	-
4	2	-	-	-	Yes	0.15
5		Yes	5	0.8	Yes	0.15
6		Yes	5	0.8	-	-
7	3	-	-	-	Yes	0.15
8		Yes	7	0.8	Yes	0.15
9		Yes	7	0.8	-	-
10	4	-	-	-	Yes	0.15
11		Yes	10	0.8	Yes	0.15
12		Yes	10	0.8	-	-

3.6 Hazard Analysis

All of the model testing will be done in the wave tank located in the Ocean & Coastal Engineering Lab. So for all lab works, all health, safety & environment (HSE) regulations set for the lab must be followed. Any disobey of the regulations might cause damage to the student and also damaged the lab equipment. For example, the model will need to be lift by a crane to get it into the wave basin as it is heavy to carry. Extra caution needs to be taken while operating the crane to avoid the model from falling down and damaging any equipment in the laboratory. All HSE regulations must also be followed while running any test in the wave basin. From there, any sorts of injury or incidents can be avoided.

CHAPTER 4
RESULT & DISCUSSION

This section will briefly discuss the calculations and results achieved from the methodology.

4.1 Hydrostatic Stability Test

The hydrostatic stability test was done to check weather the model could float stable or not in the water. The calculation for hydrostatic stability will be based on the equation stated in chapter 2 and it is included in the Appendix. This test had been done during the design stage and after fabrication was completed. The test was done for both maximum and minimum loading conditions to make sure that the model will float stably in the water. Table 5 shows the result from the calculation of hydrostatic stability of the model.

Table 5 Hydrostatic Stability Results

	(1)	(2)	(2) – (1)	
Condition	*GB* (cm)	*MB* (cm)	*MG* (cm)	Remarks
Maximum	3.59	9.79	6.20	>0, model will float stably.
Minimum	14.79	134.69	119.91	>0, model will float stably.

The hydrostatic calculations for both maximum and minimum condition were different as per the difference in draft of both conditions.

From the result it shows that the semi-submersible can float stable in water and from the model testing it has proven the calculation done was correct. From Figure 9 in the previous chapter, picture shows that the model was floating stable and it is not tilting to any direction while being in the water.

4.2 Wave Test

The semi-submersible model was tested with two types of wave; regular wave and random wave.

4.2.1 Regular Wave Test

Table 3 from the Chapter 3 before shows all 31 tests planned and all of it have already completed. Out of the 31 tests, 26 of them were done under regular wave condition and all tests video have been analyzed. Graphs for all 26 tests are already plotted and are included in this report. Figure 17 to 42 shows graph results for all tests. From 26 tests results reported, the results from only three tests are analyzed here. They are tests 4, 16 and 26. Note that the only difference between Test 4 and Test 16 is in the loading conditions, the difference between Test 4 and Test 26 is in the wave periods, and the difference between Test 16 and Test 26 is in both loading conditions and wave period. The tests wave periods are 0.8 sec and 1.25 sec corresponds to prototype wave periods of 8 sec and 12.5 sec. These are closed to the design values mentioned in methodology before. Figure 43 shows the combined surge, heave and pitch for all three tests.

The series of wave tests is to analyzed three modes of motion for each test: surge, heave and pitch. Figure 16 below is the convention used to plot all three modes of motions.

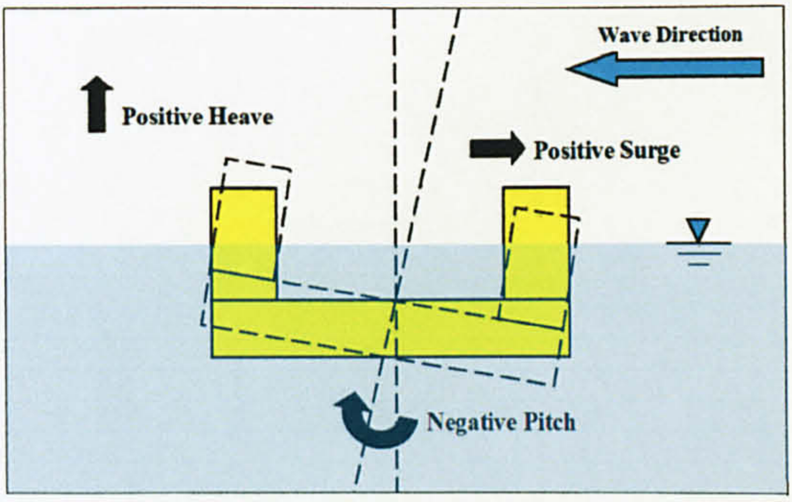

Figure 16 Convention Used

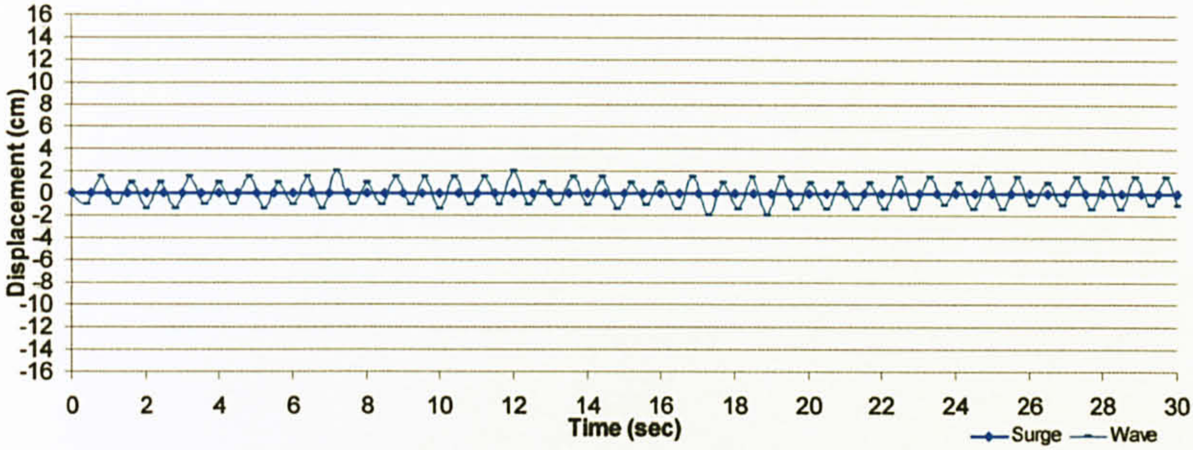

Figure 17a: Surge Response

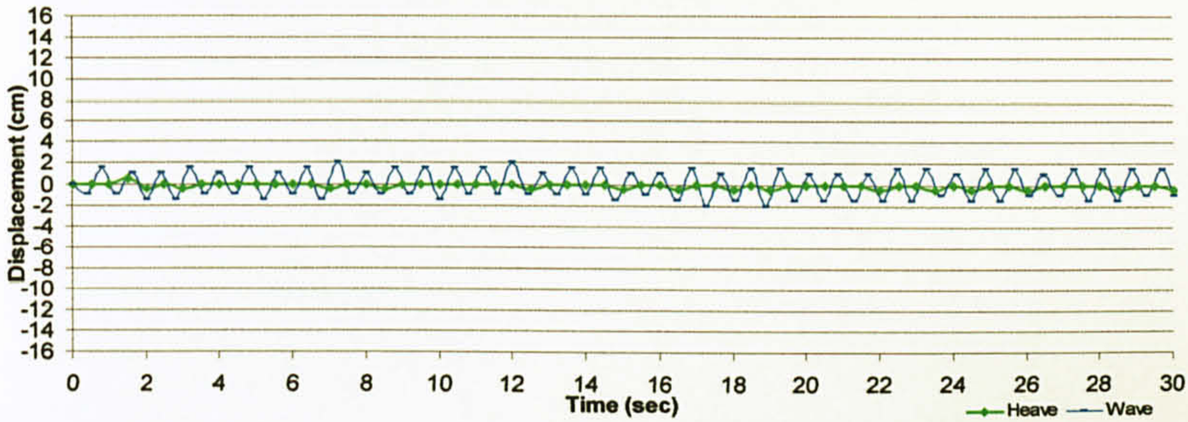

Figure 17b: Heave Response

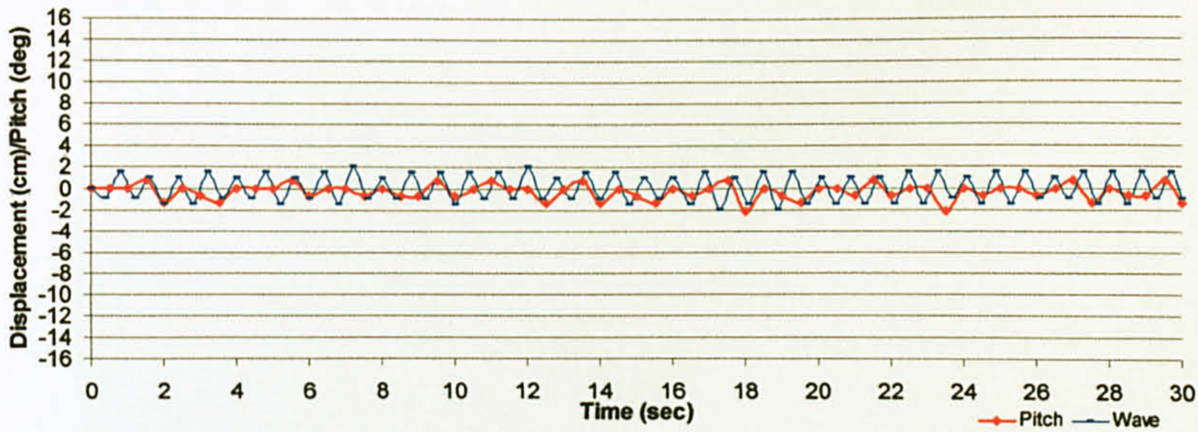

Figure 17c: Pitch Response

Figure 17 The Model Response in TEST 1

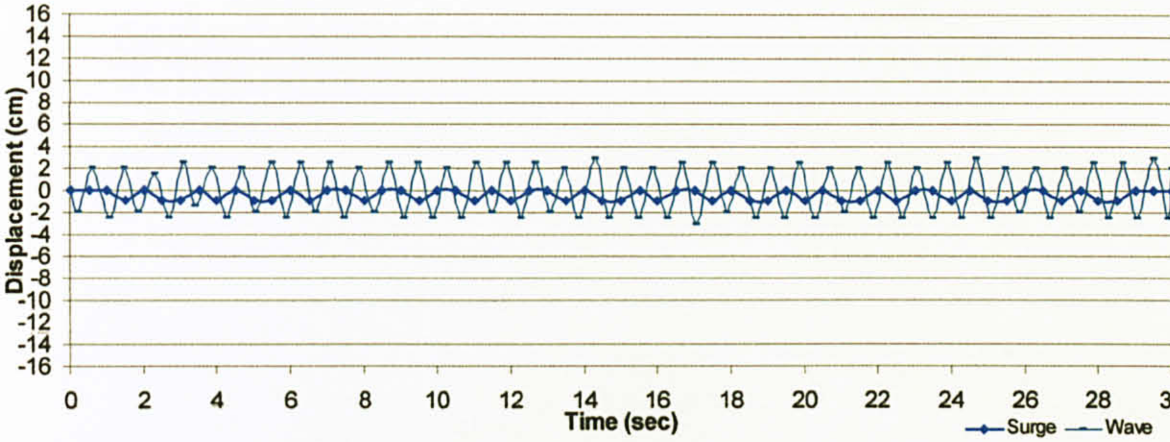

Figure 18a: Surge Response

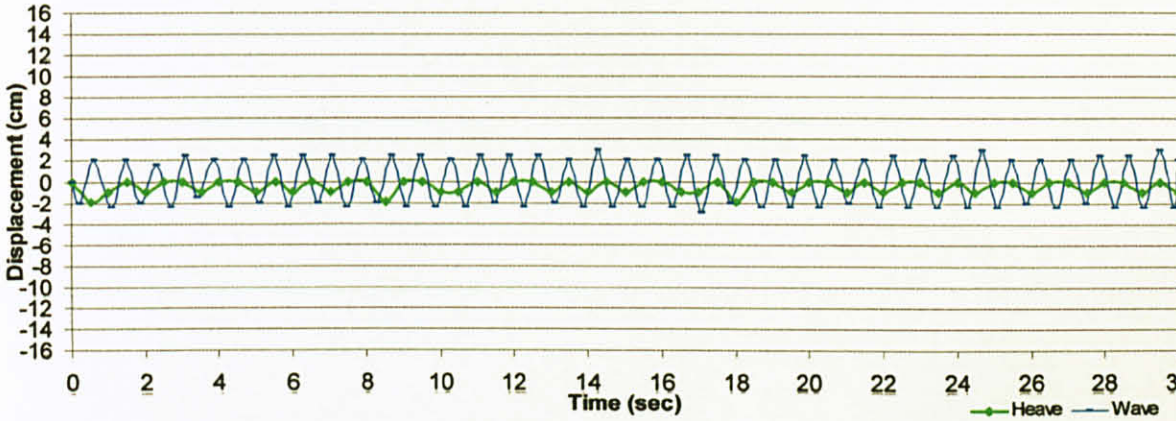

Figure 18b: Heave Response

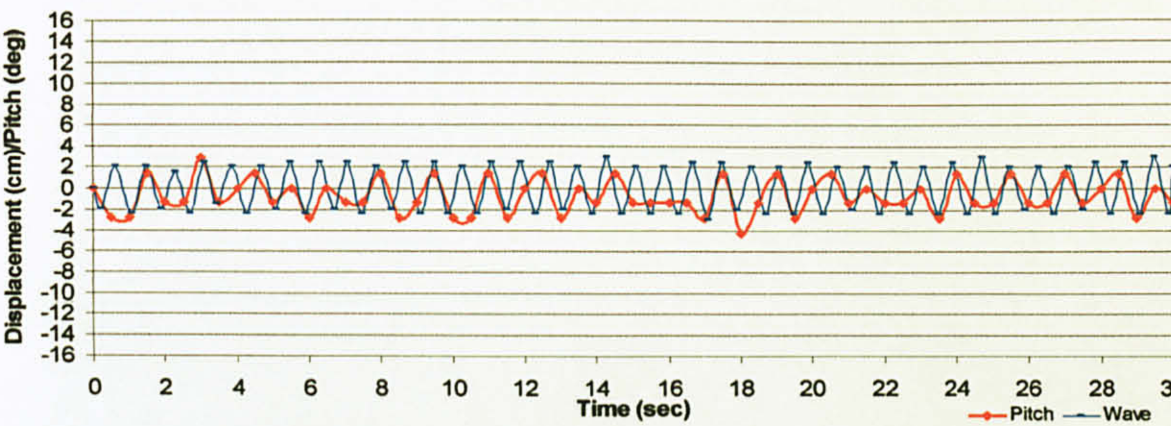

Figure 18c: Pitch Response

Figure 18 The Model Response in TEST 2

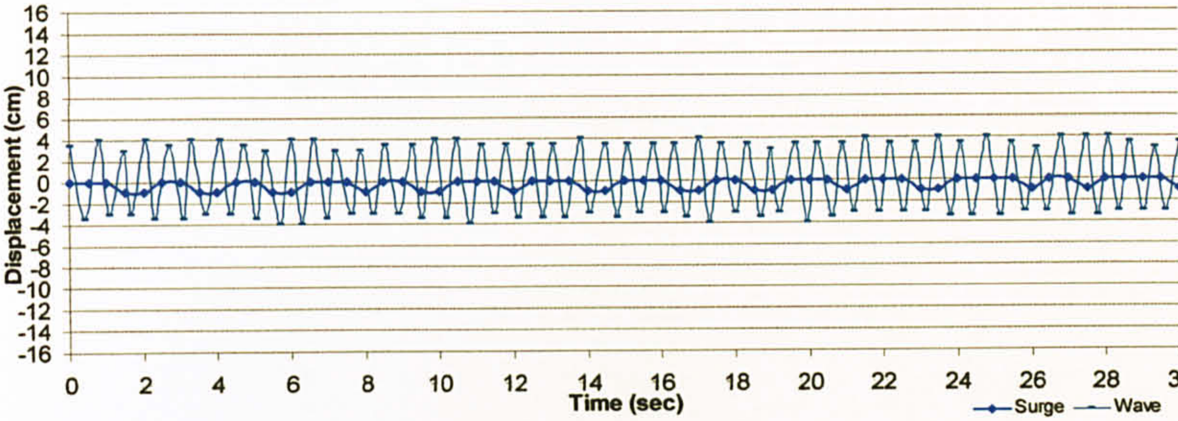

Figure 19a: Surge Response

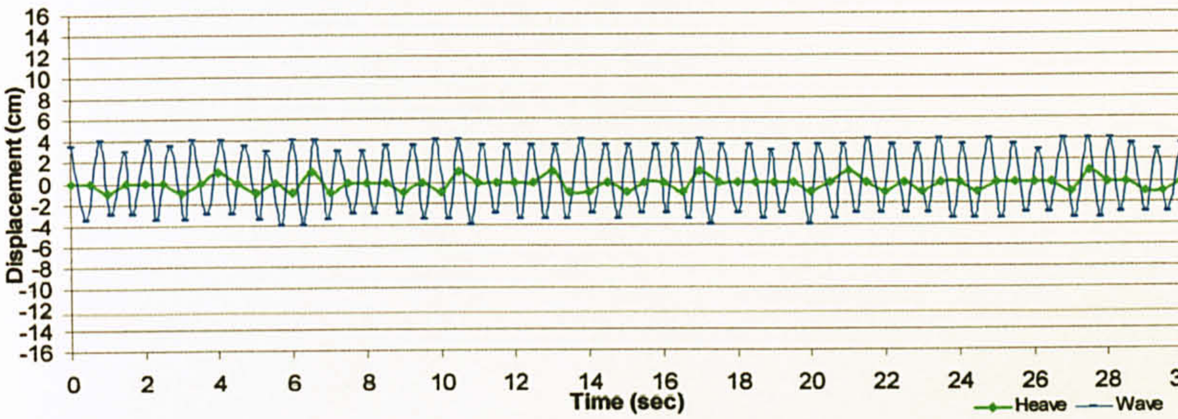

Figure 19b: Heave Response

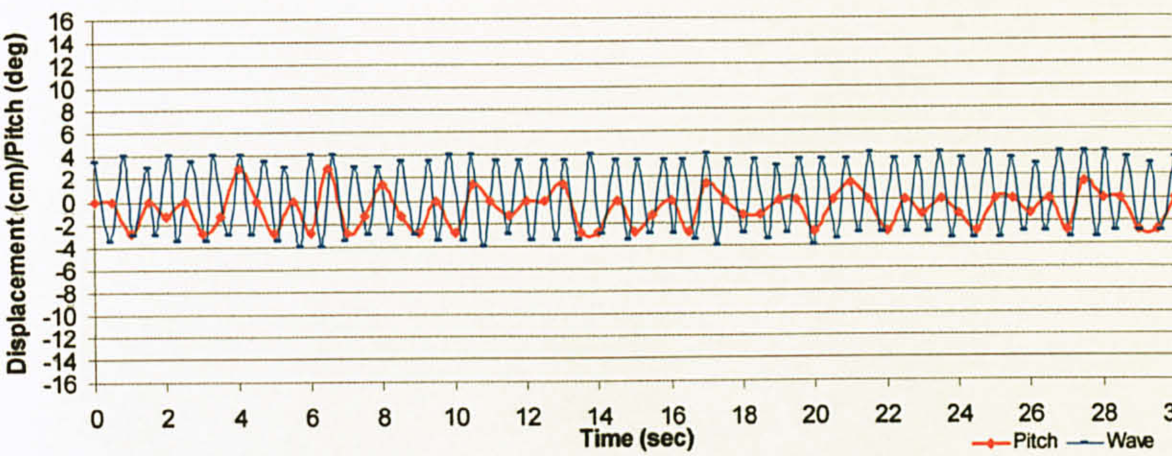

Figure 19c: Pitch Response

Figure 19 The Model Response in TEST 3

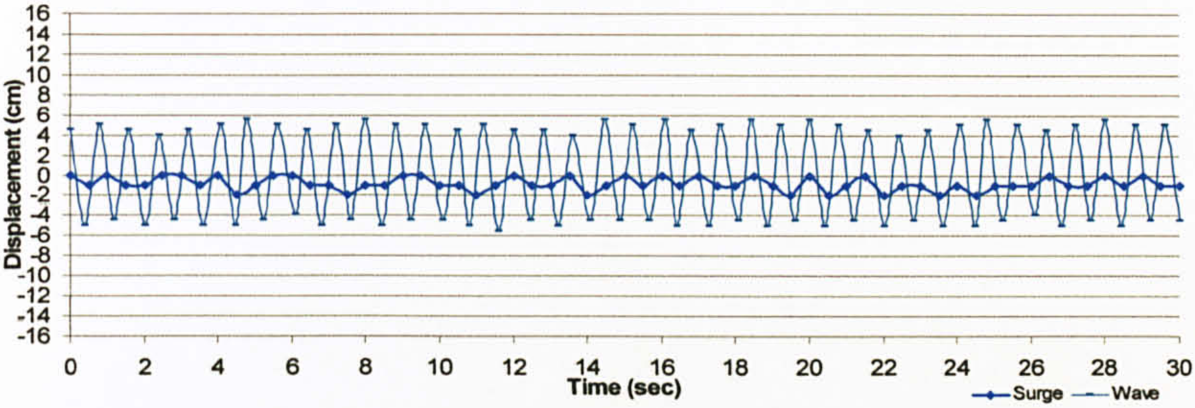

Figure 20a: Surge Response

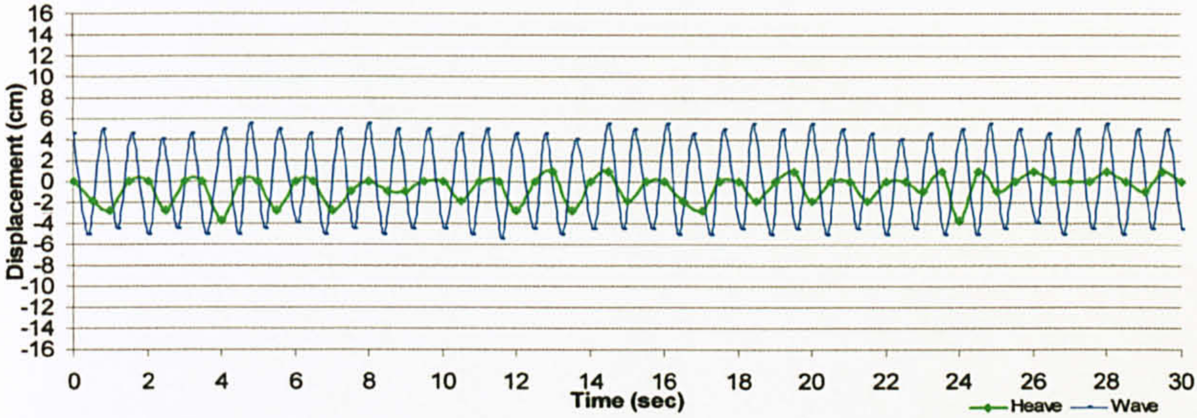

Figure 20b: Heave Response

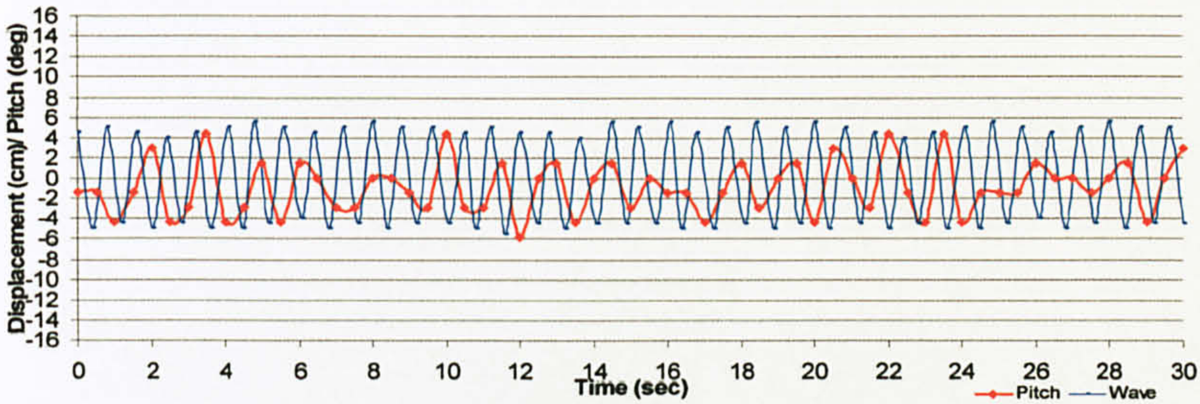

Figure 20c: Pitch Response

Figure 20 The Model Response in TEST 4

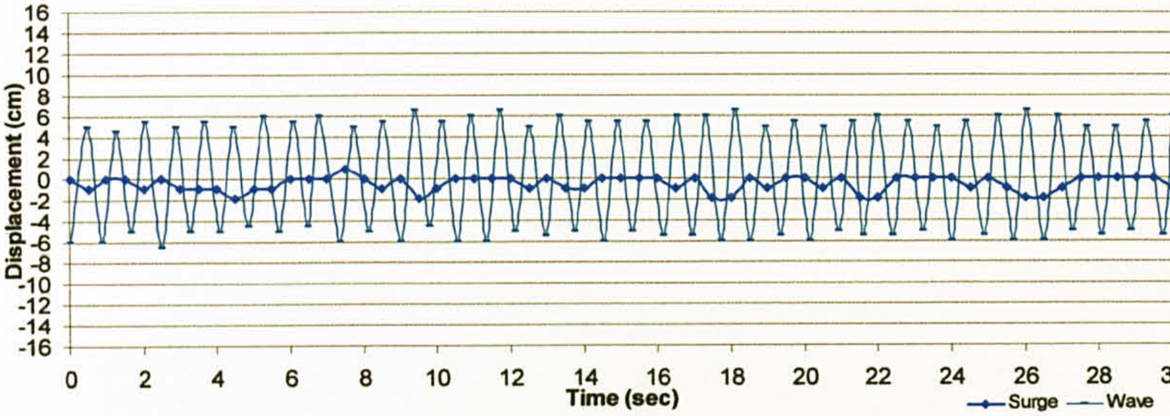

Figure 21a: Surge Response

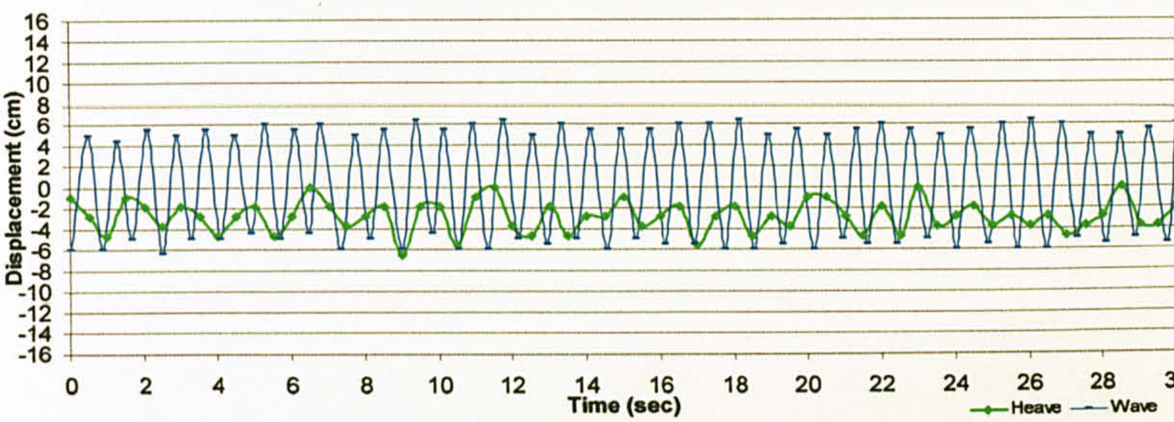

Figure 21b: Heave Response

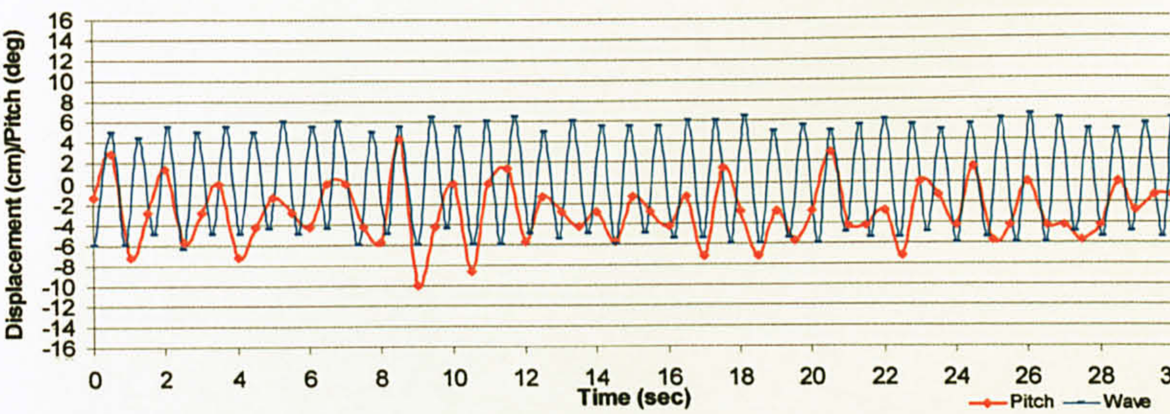

Figure 21c: Pitch Response

Figure 21 The Model Response in TEST 5

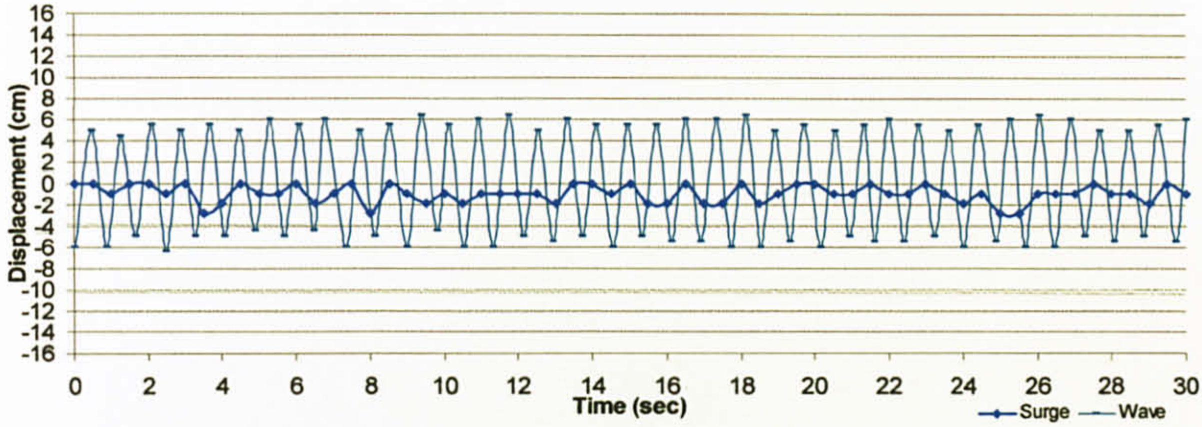

Figure 22a: Surge Response

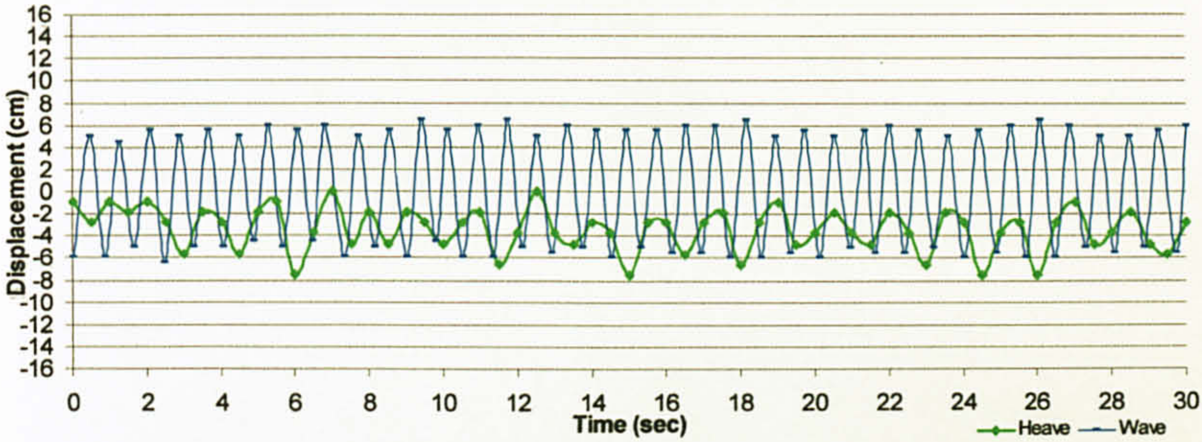

Figure 22b: Heave Response

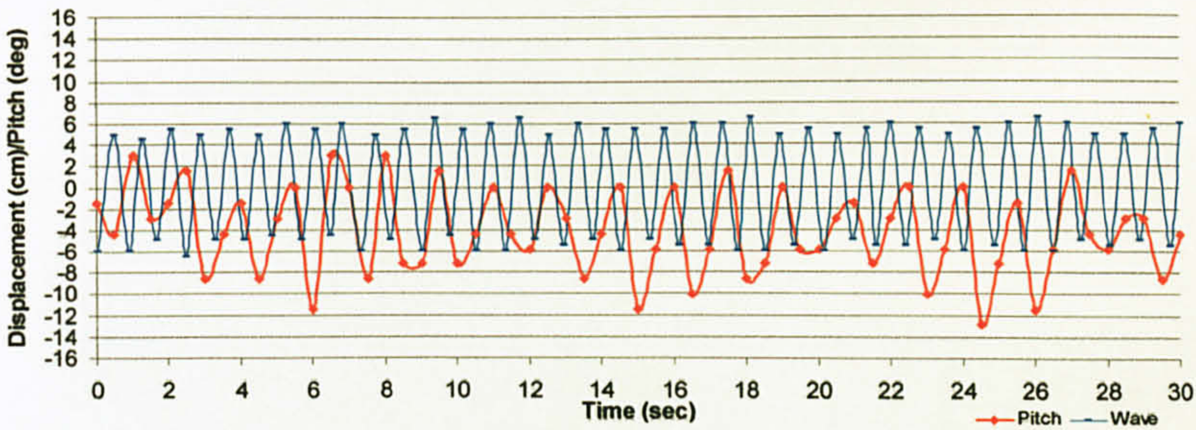

Figure 22c: Pitch Response

Figure 22 The Model Response in TEST 6

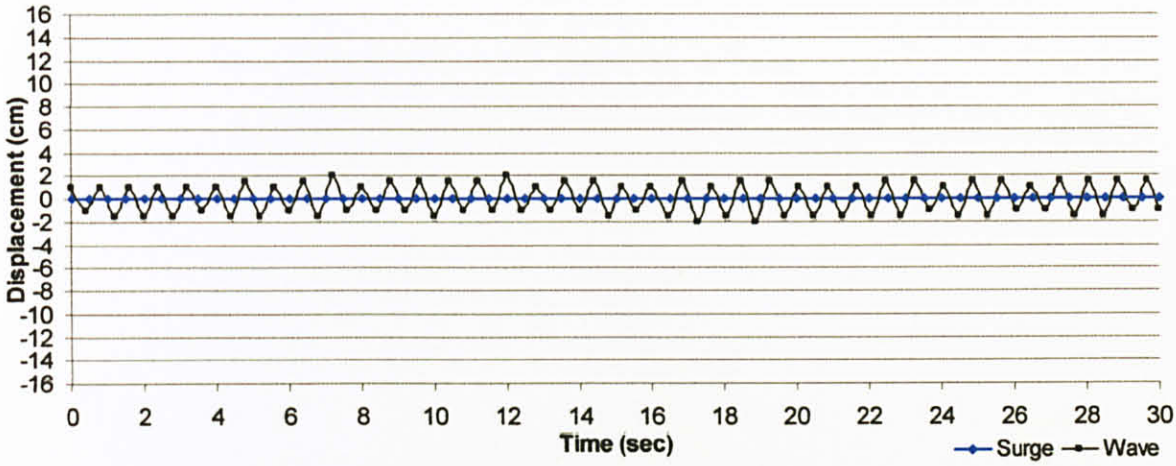

Figure 23a: Surge Response

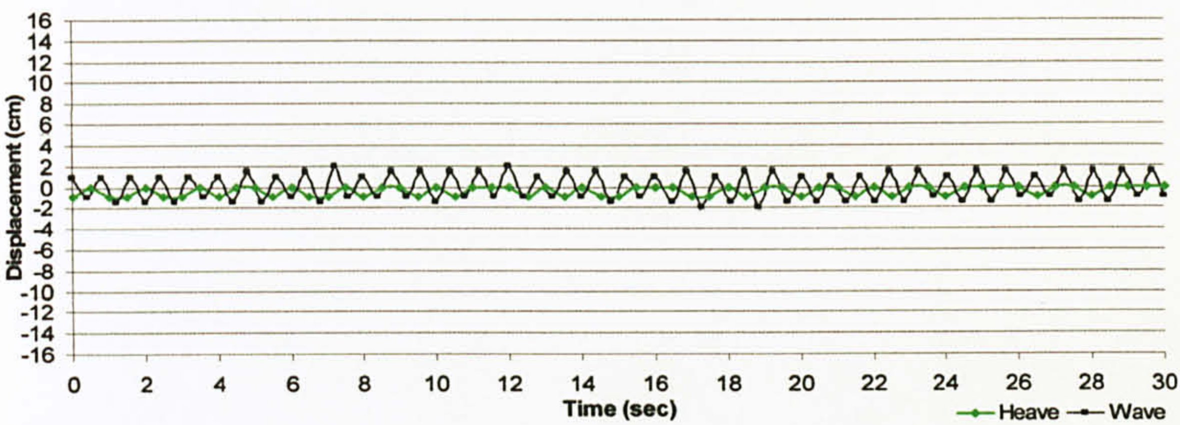

Figure 23b: Heave Response

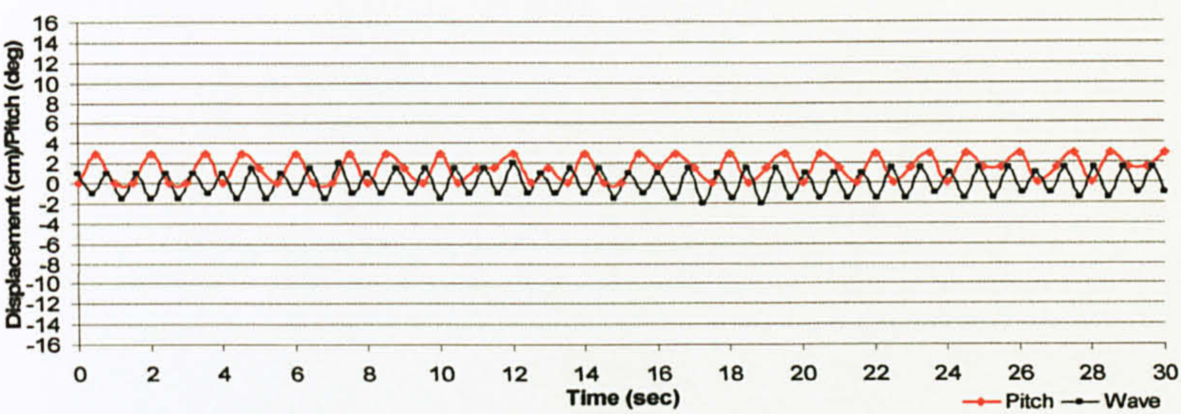

Figure 23c: Pitch Response

Figure 23 The Model Response in TEST 7

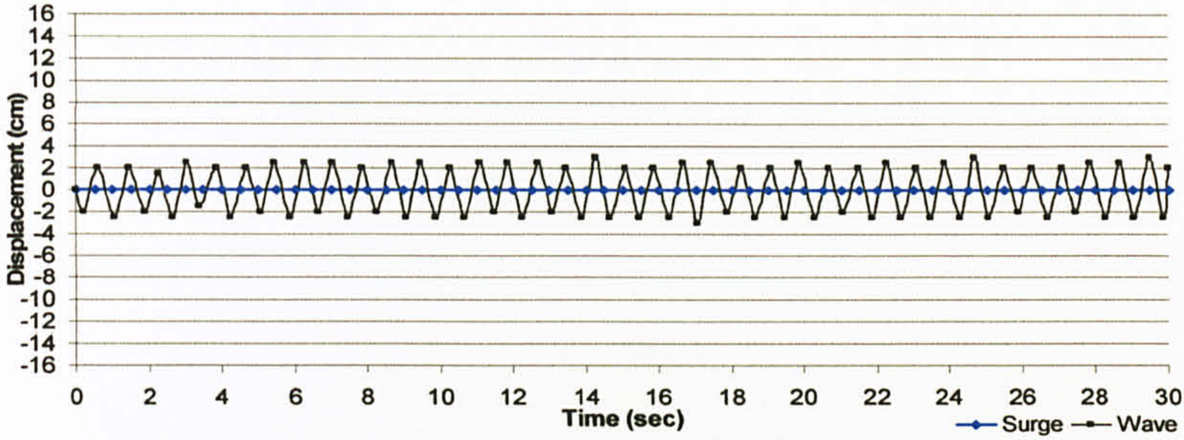

Figure 24a: Surge Response

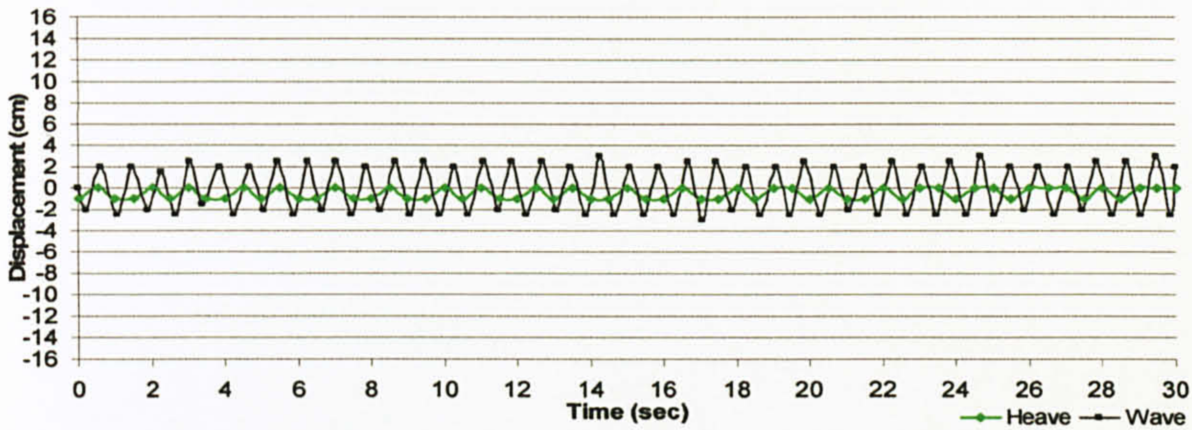

Figure 24b: Heave Response

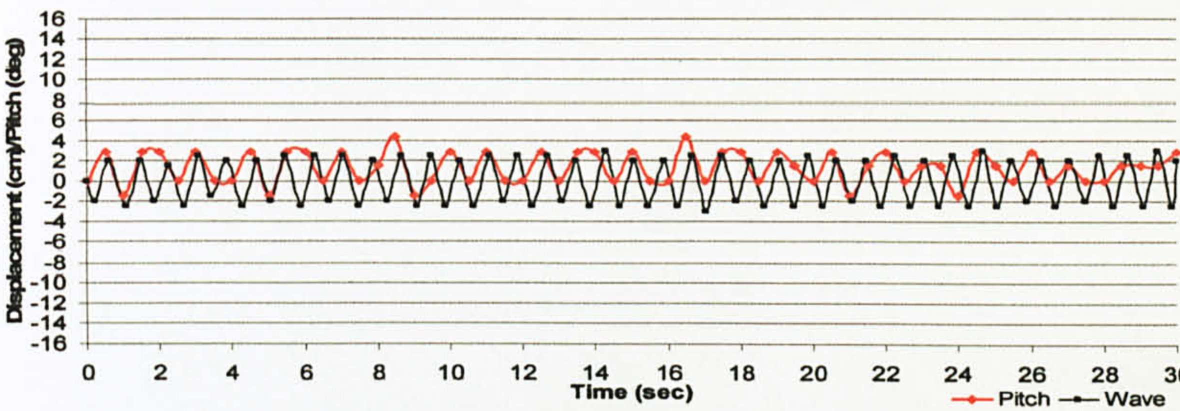

Figure 24c: Pitch Response

Figure 24 The Model Response in TEST 8

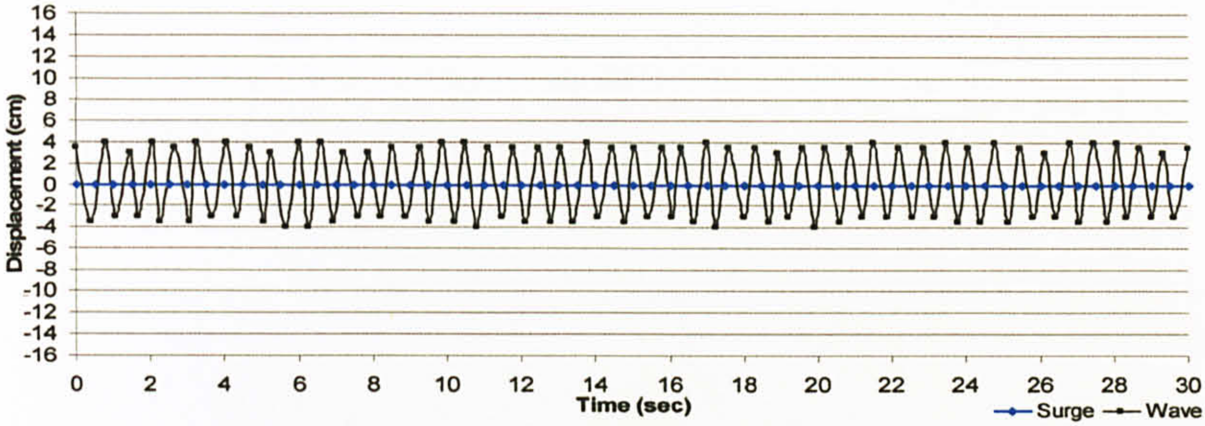

Figure 25a: Surge Response

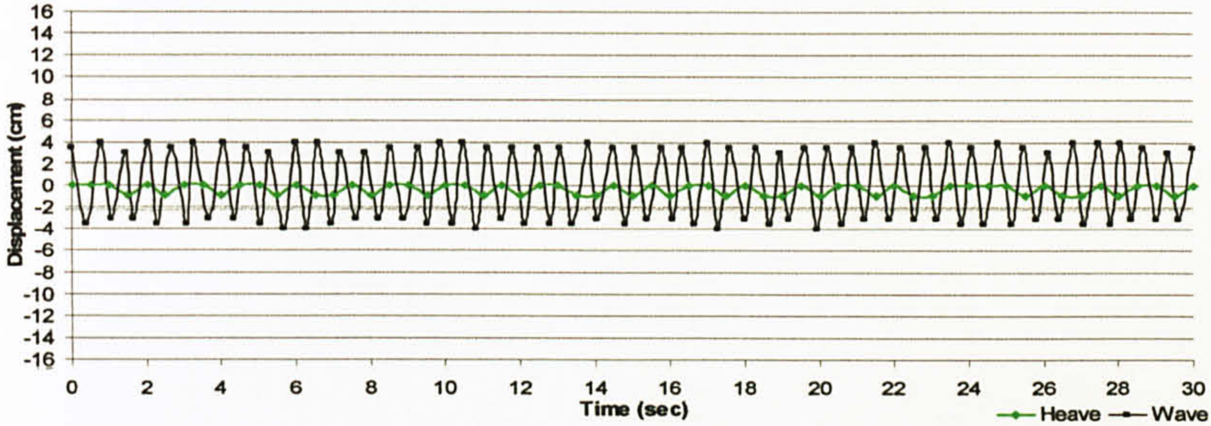

Figure 25b: Heave Response

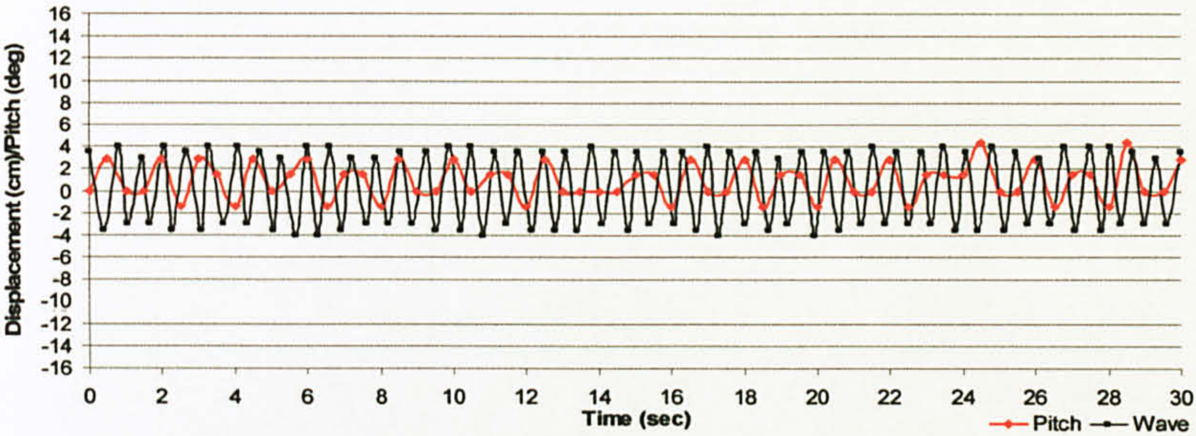

Figure 25c: Pitch Response

Figure 25 The Model Response in TEST 9

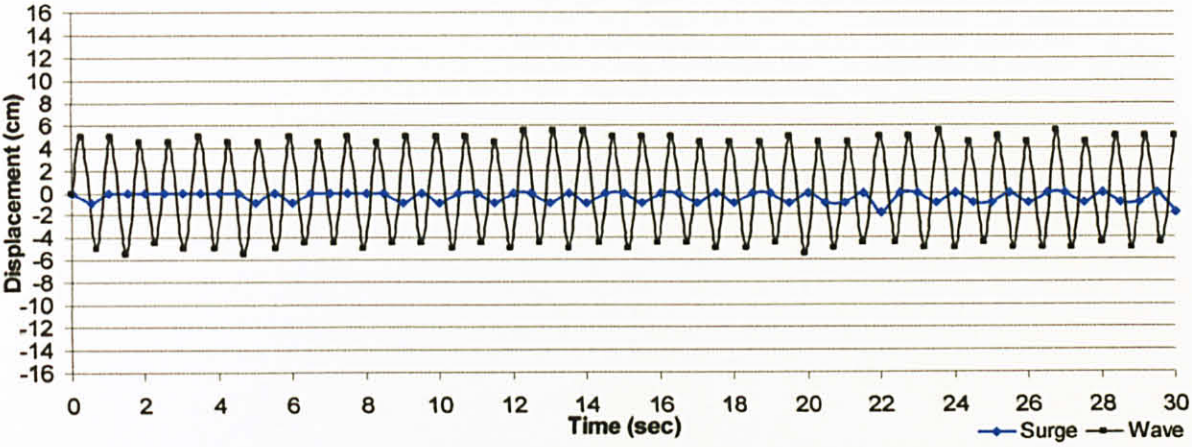

Figure 26a: Surge Response

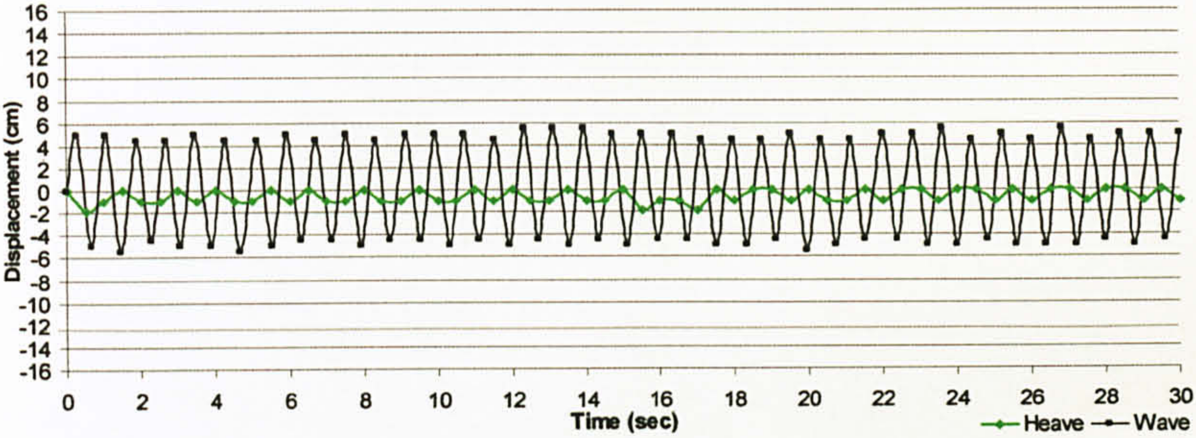

Figure 26b: Heave Response

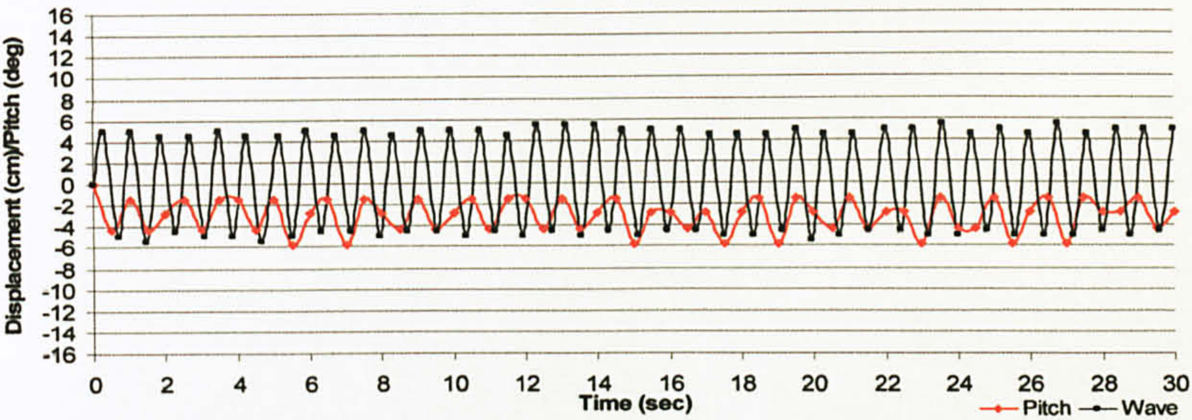

Figure 26c: Pitch Response

Figure 26 The Model Response in TEST 10

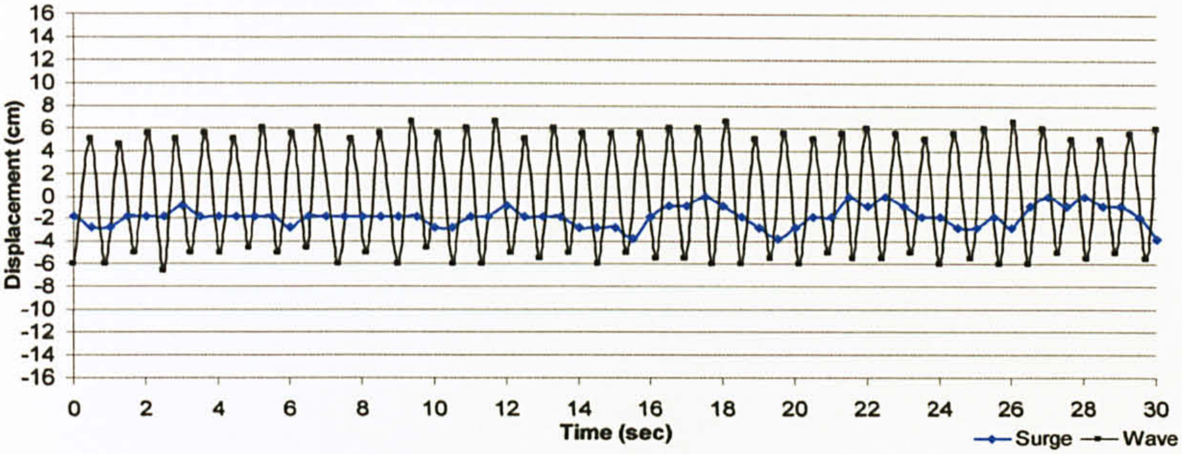

Figure 27a: Surge Response

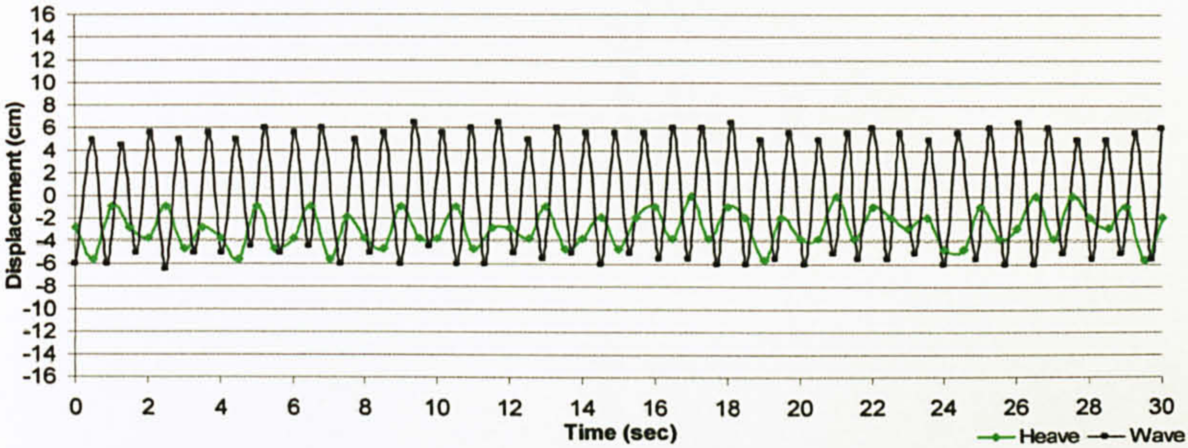

Figure 27b: Heave Response

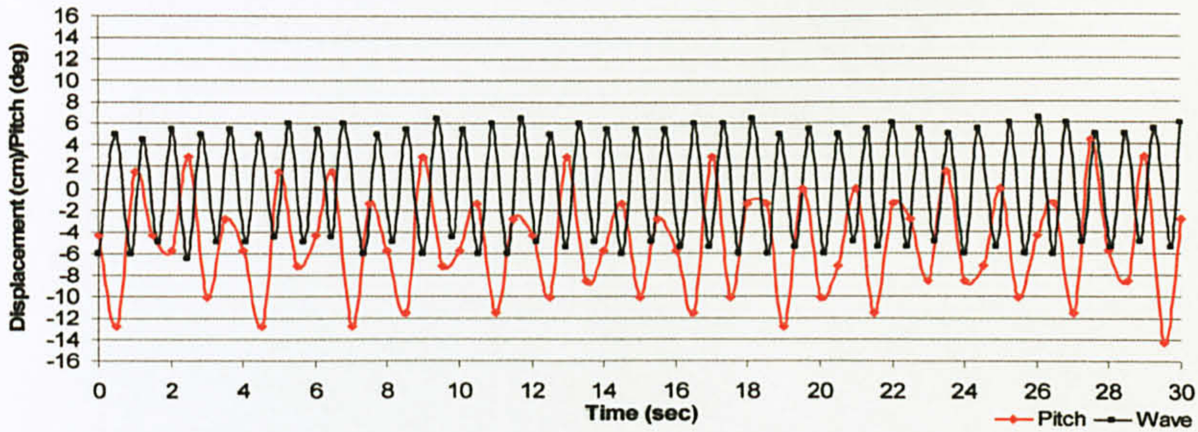

Figure 27c: Pitch Response

Figure 27 The Model Response in TEST 11

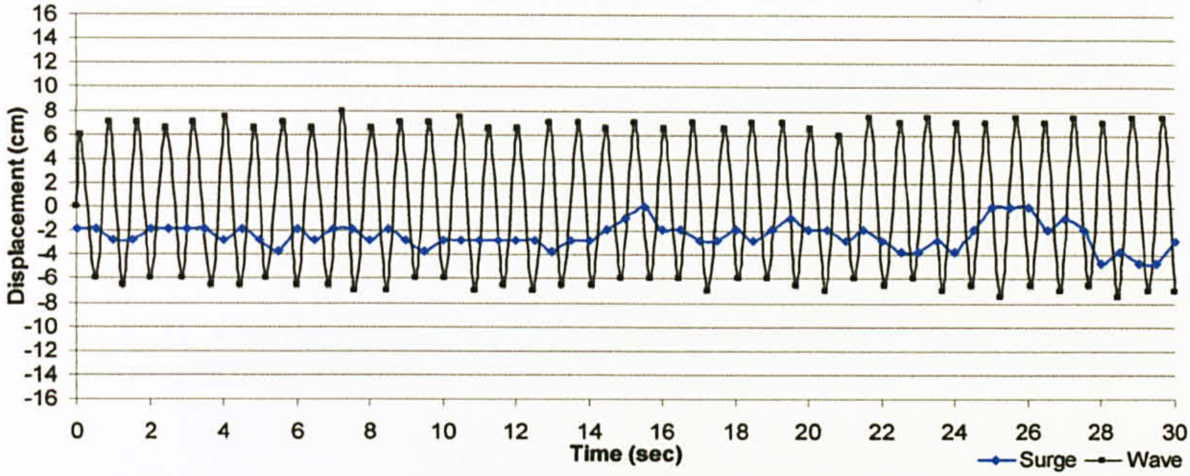

Figure 28a: Surge Response

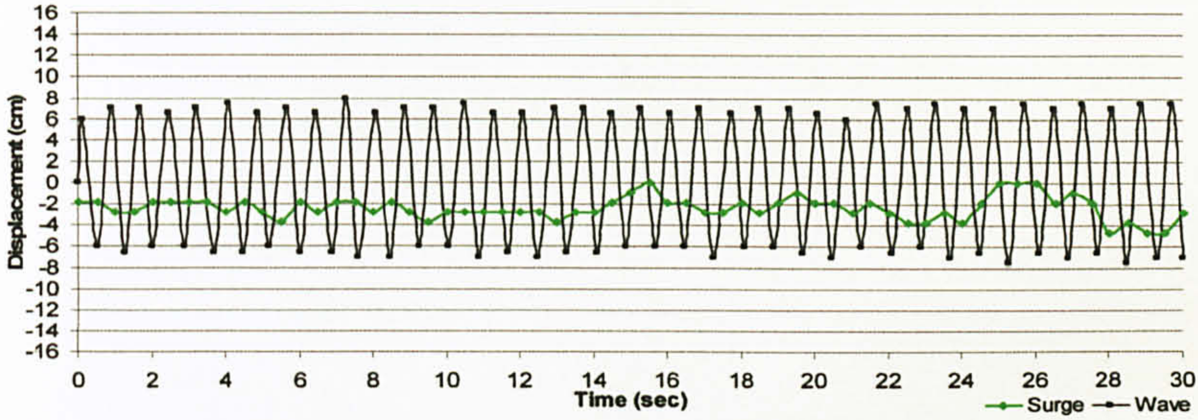

Figure 28b: Heave Response

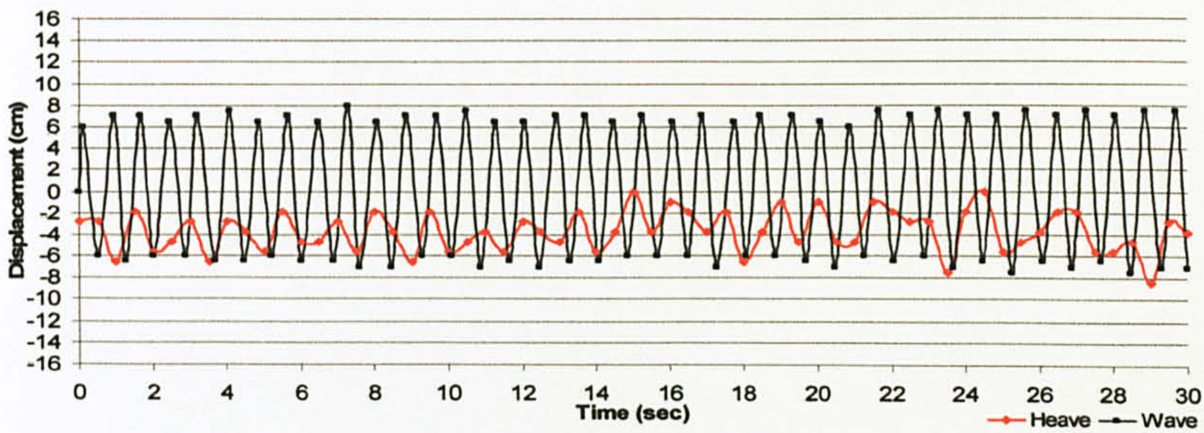

Figure 28c: Pitch Response

Figure 28 The Model Response in TEST 12

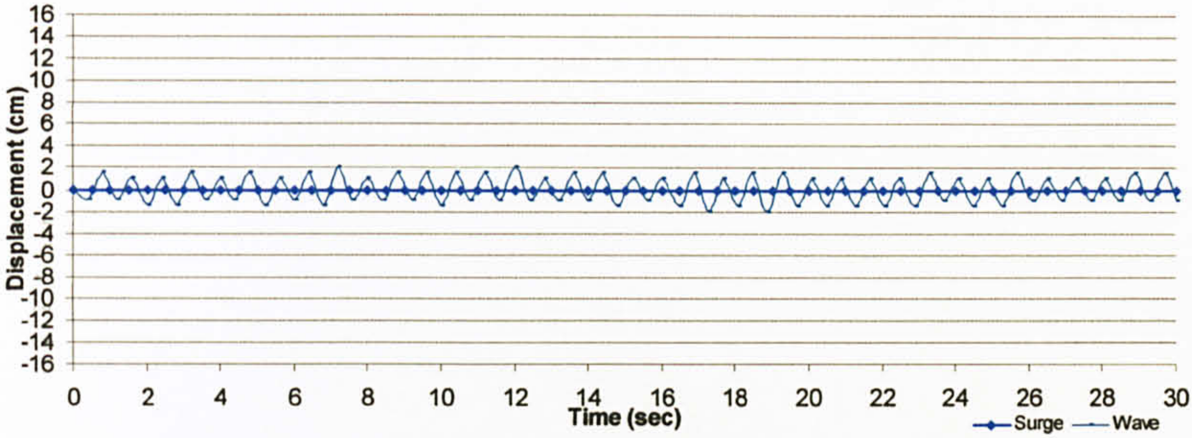

Figure 29a: Surge Response

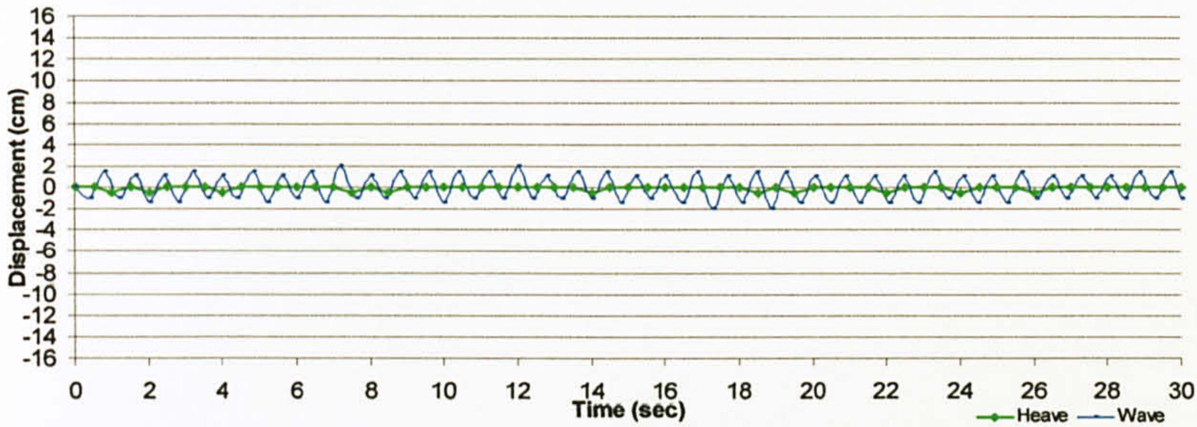

Figure 29b: Heave Response

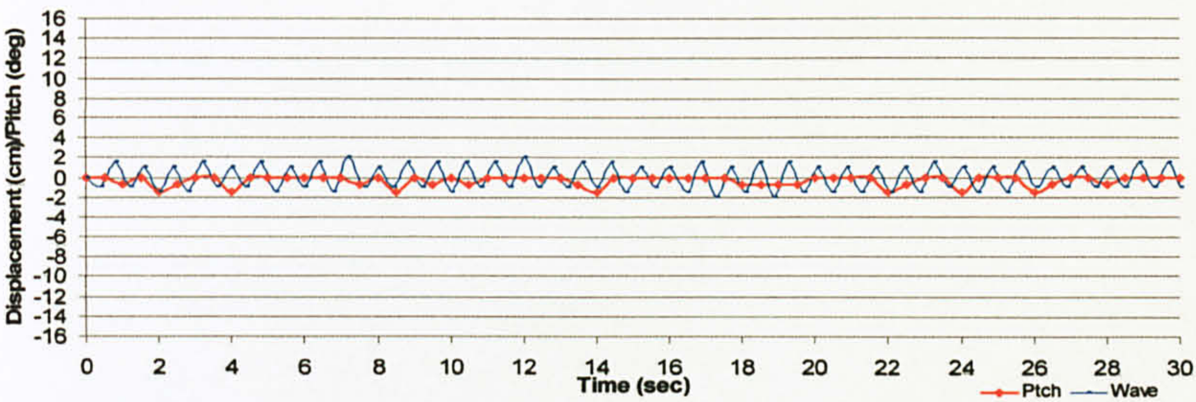

Figure 29c: Pitch Response

Figure 29 The Model Response in TEST 13

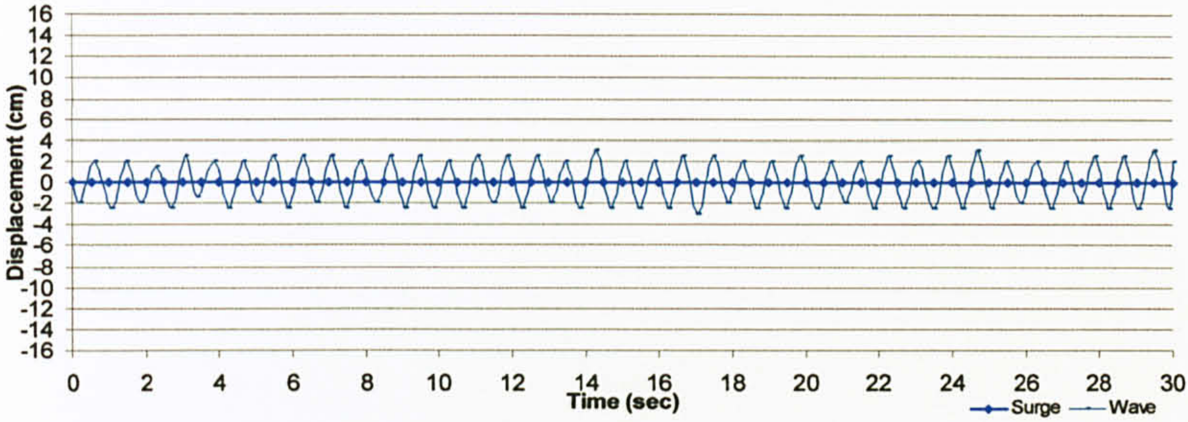

Figure 30a: Surge Response

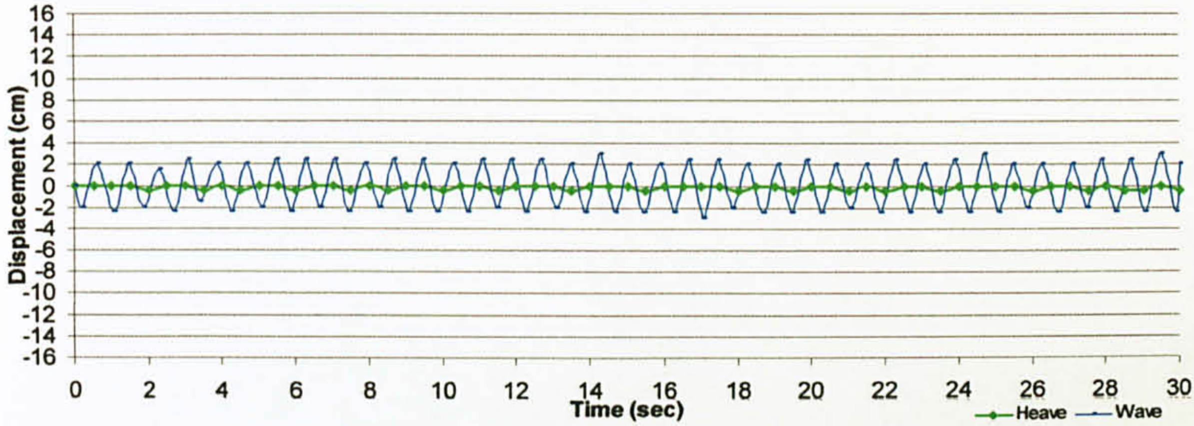

Figure 30b: Heave Response

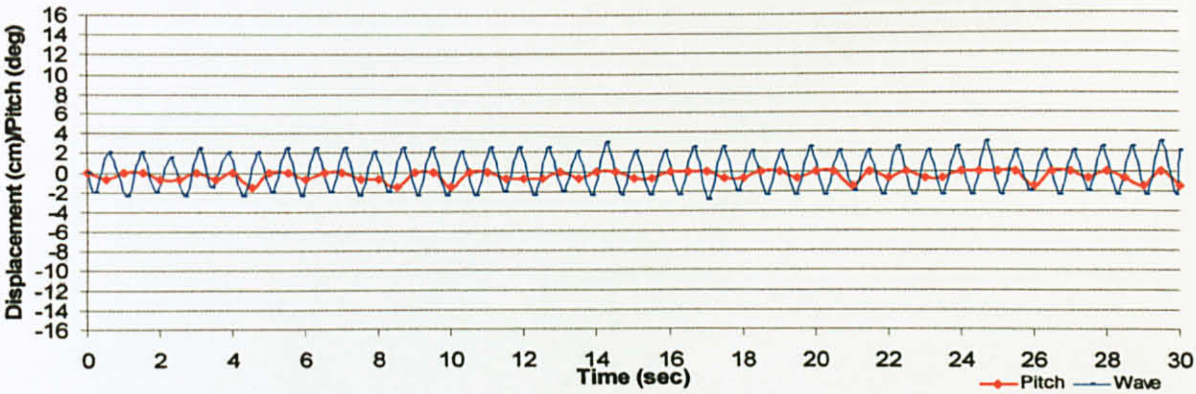

Figure 30c: Pitch Response

Figure 30 The Model Response in TEST 14

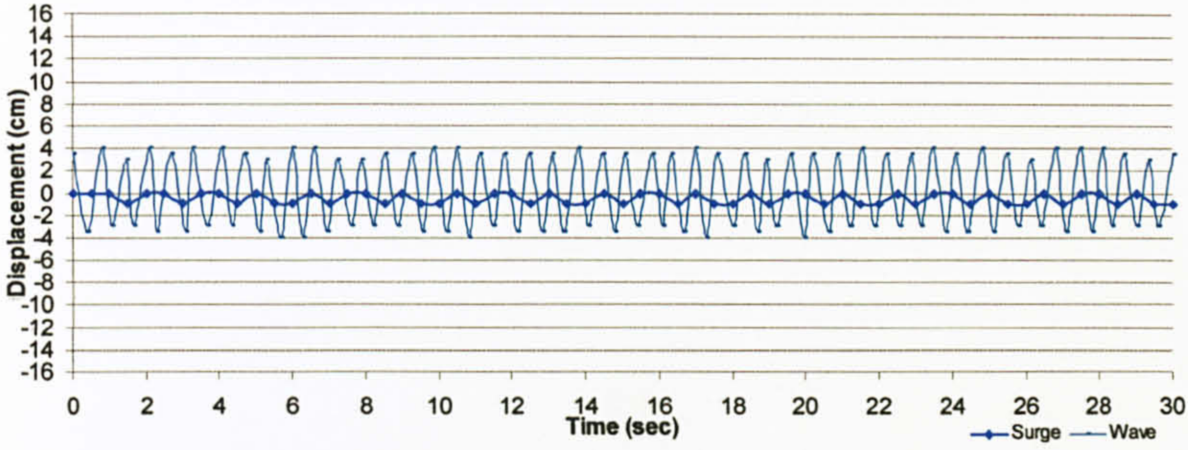

Figure 31a: Surge Response

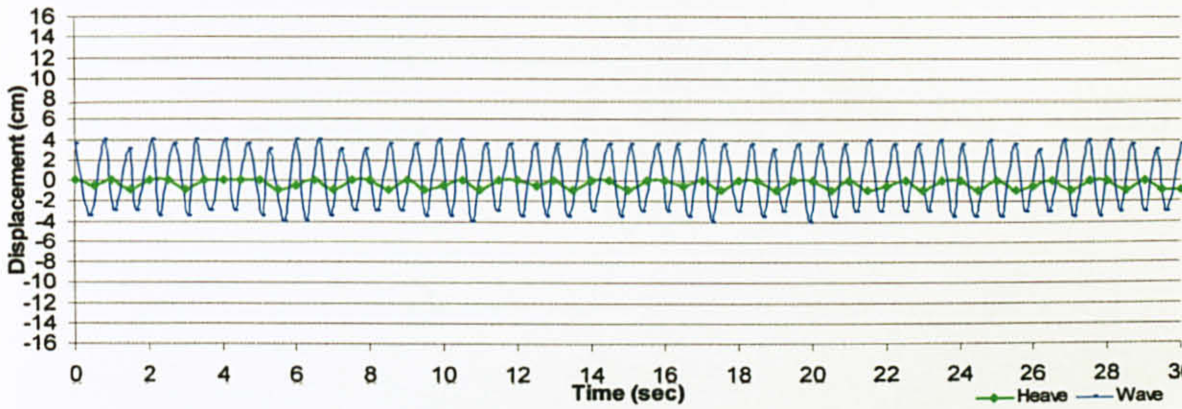

Figure 31b: Heave Response

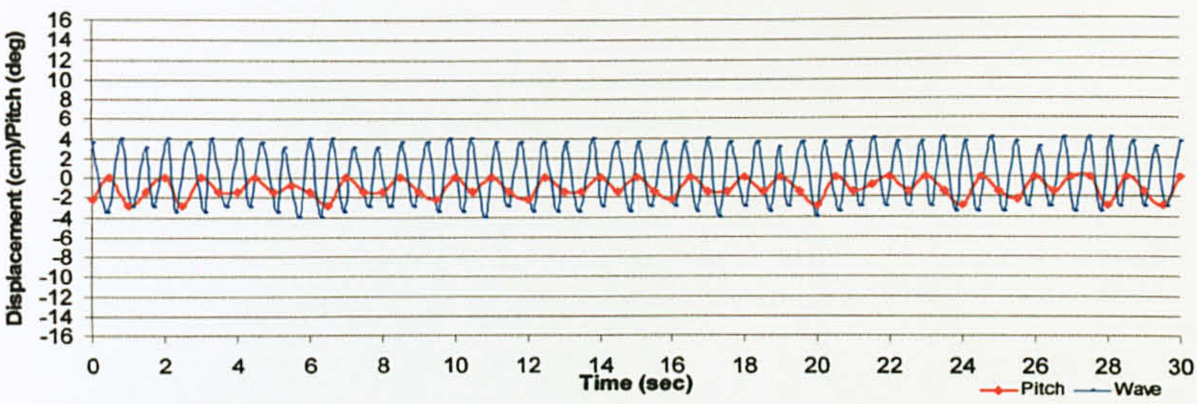

Figure 31c: Pitch Response

Figure 31 The Model Response in TEST 15

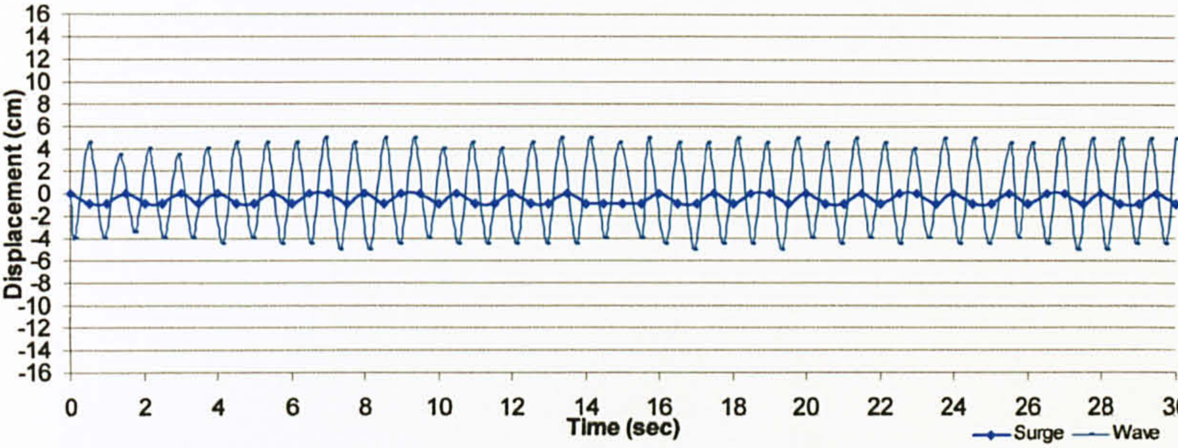

Figure 32a: Surge Response

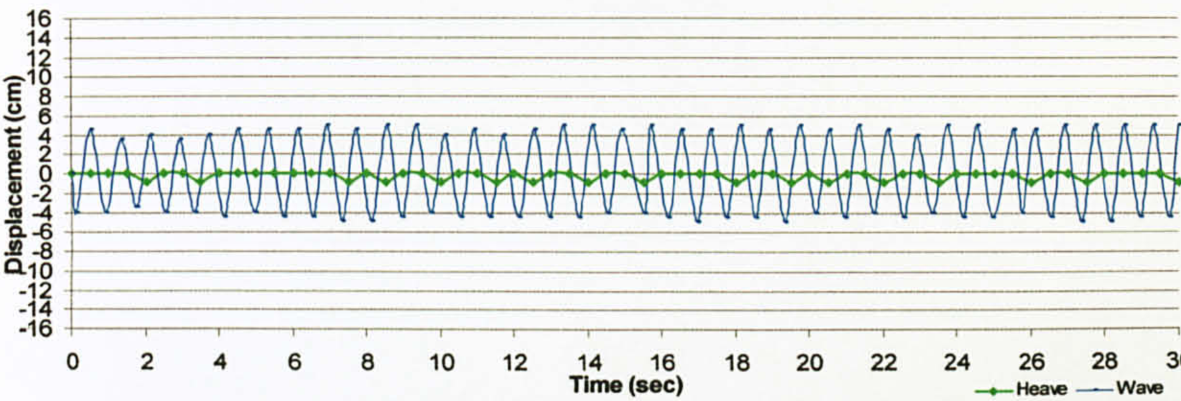

Figure 32b: Heave Response

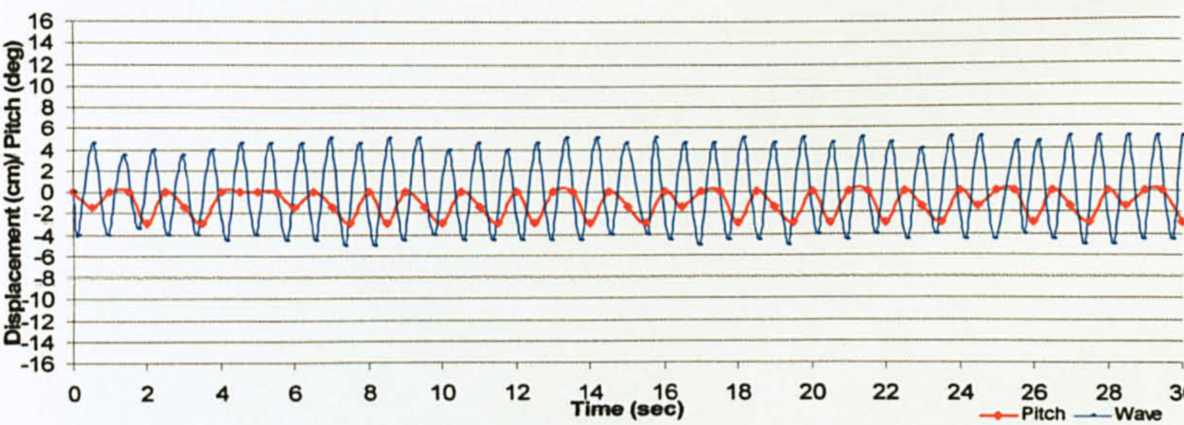

Figure 32c: Pitch Response

Figure 32 The Model Response in TEST 16

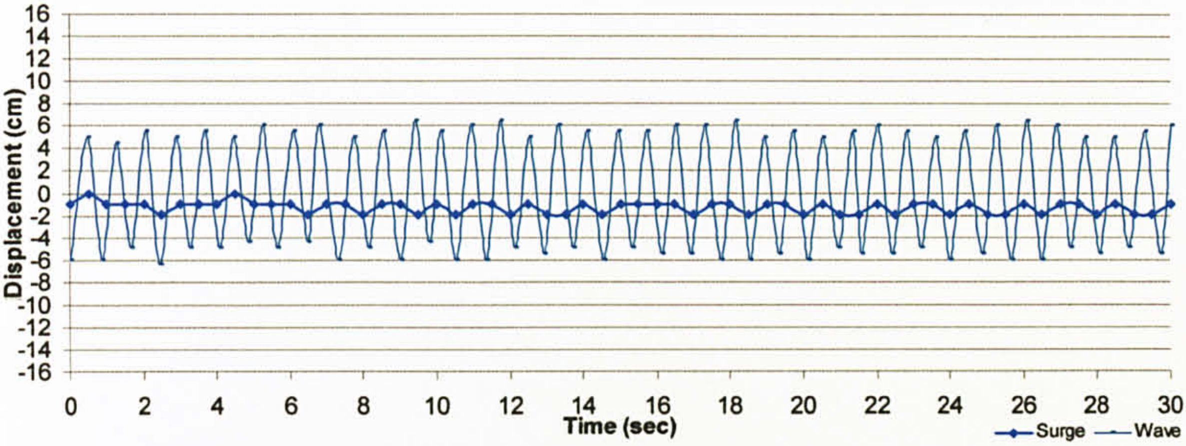

Figure 33a: Surge Response

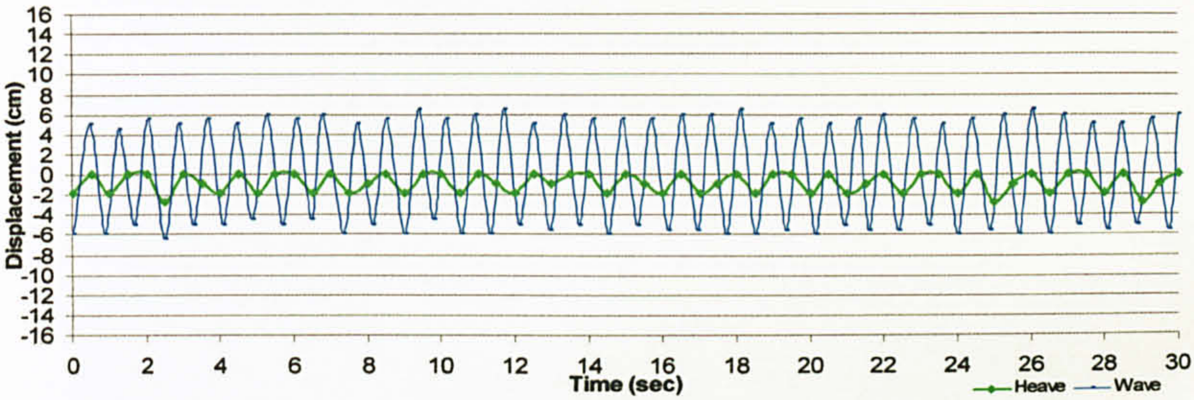

Figure 33b: Heave Response

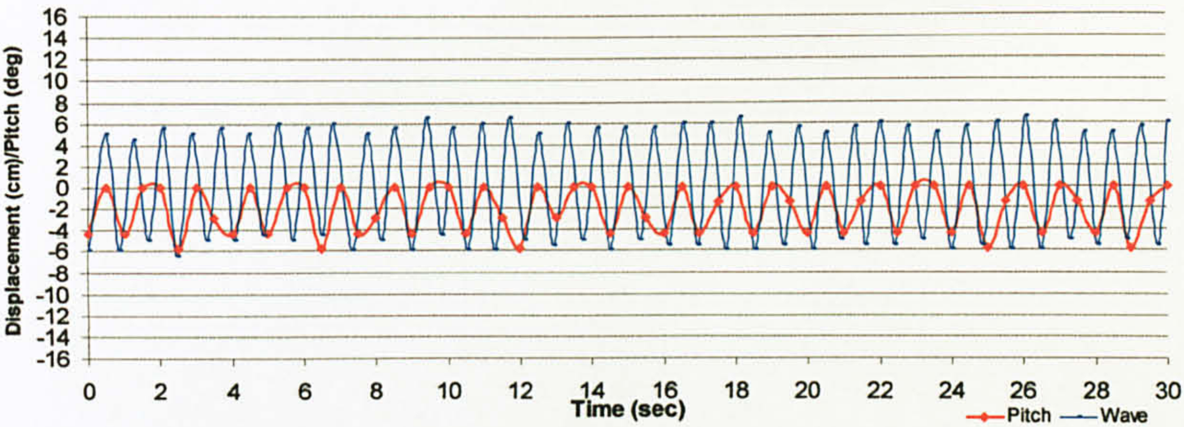

Figure 33c: Pitch Response

Figure 33 The Model Response in TEST 17

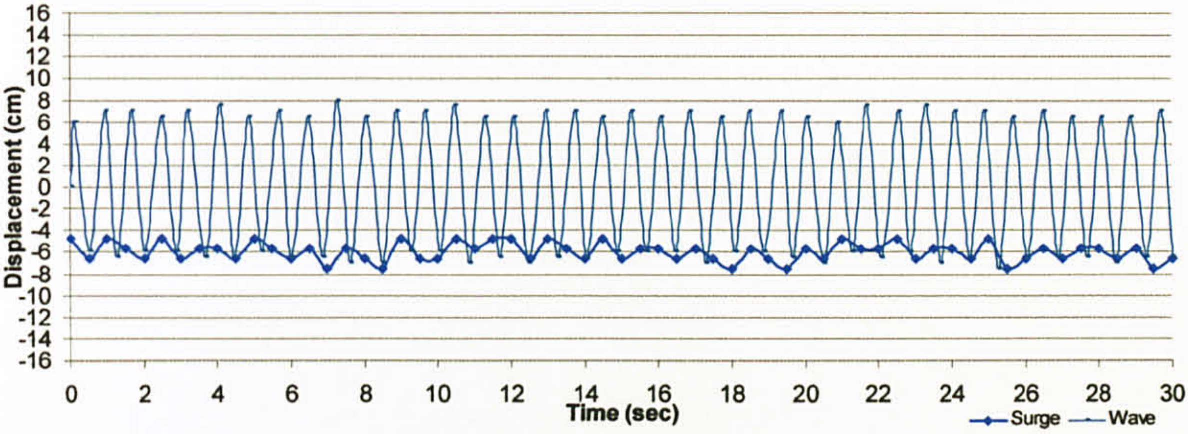

Figure 34a: Surge Response

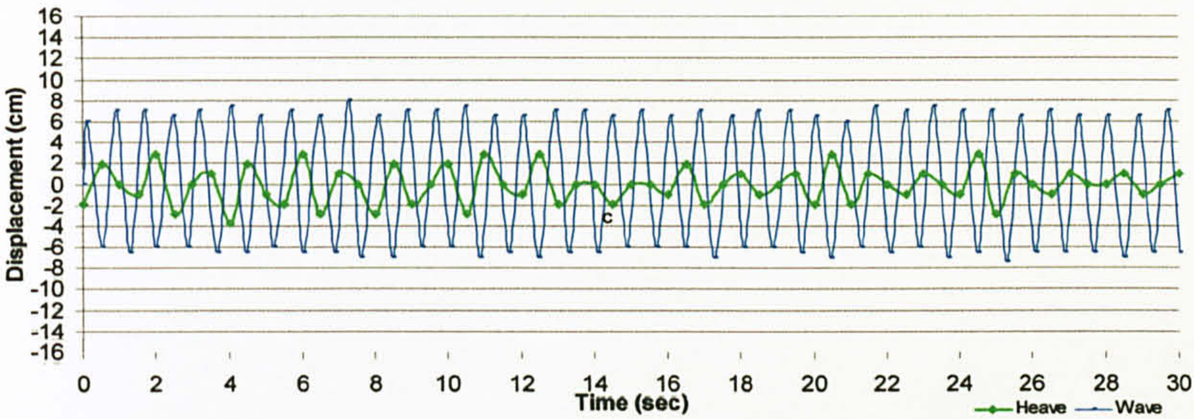

Figure 34b: Heave Response

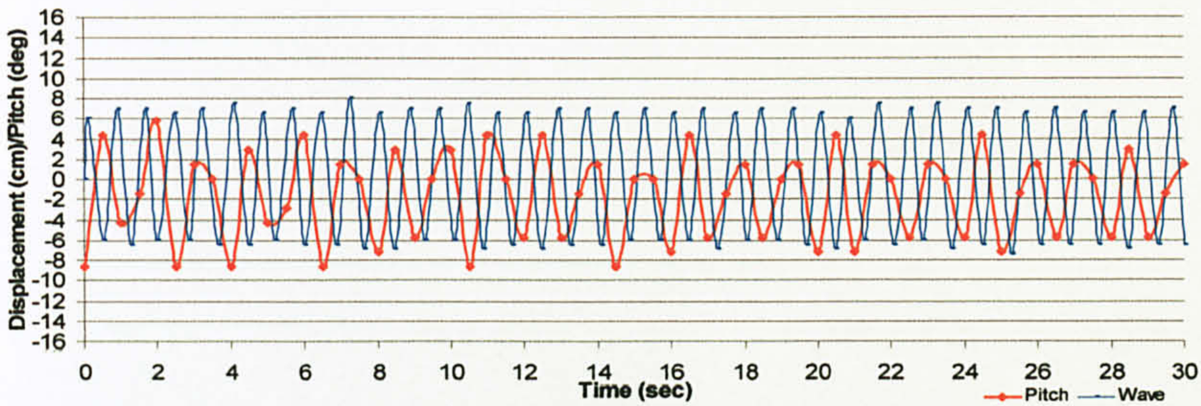

Figure 34c: Pitch Response

Figure 34 The Model Response in TEST 18

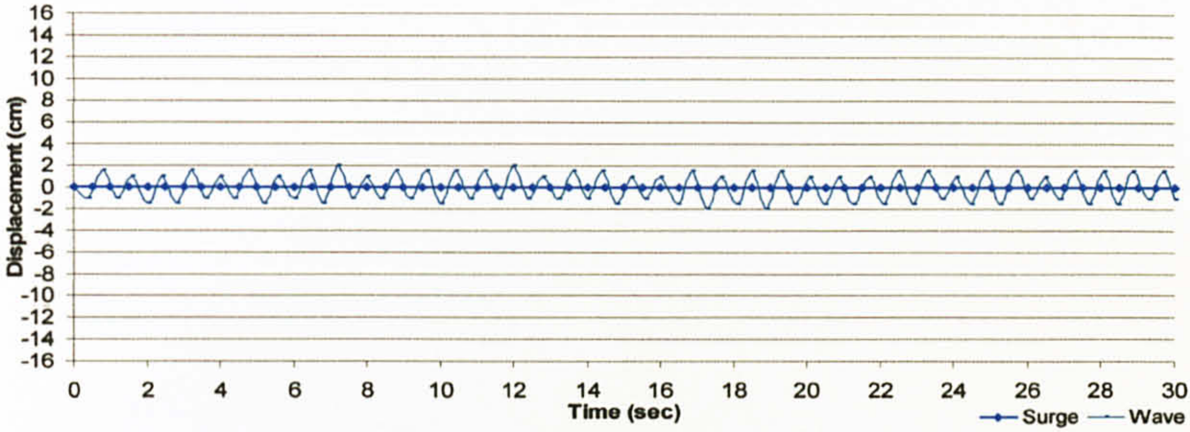

Figure 35a: Surge Response

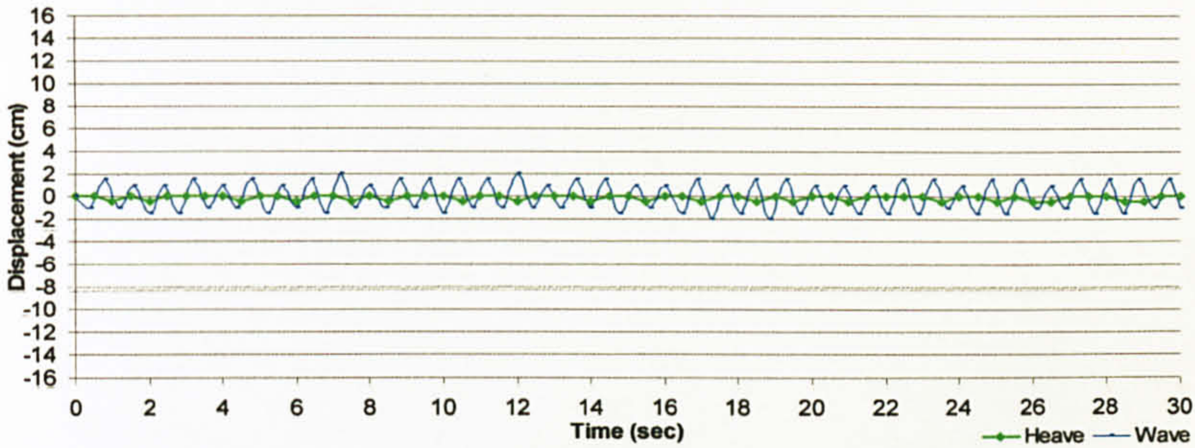

Figure 35b: Heave Response

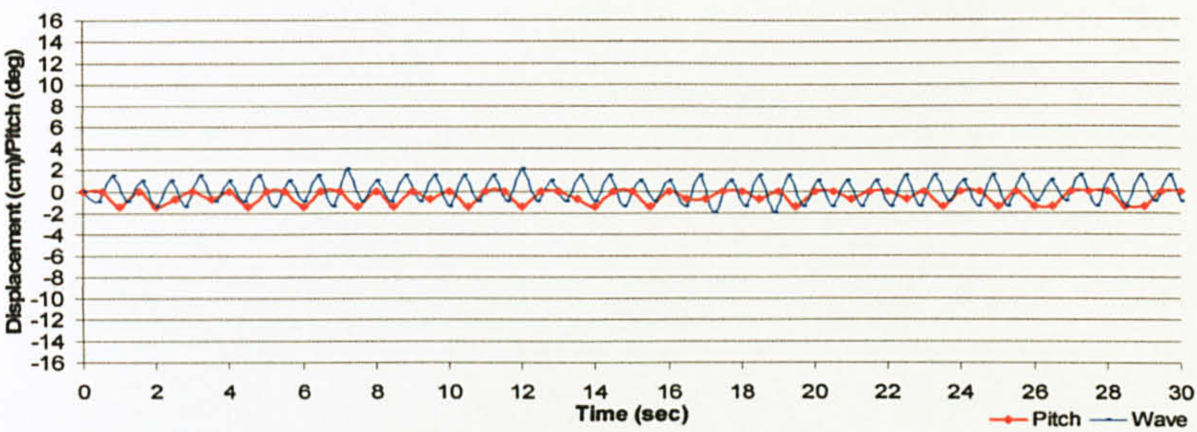

Figure 35c: Pitch Response

Figure 35 The Model Response in TEST 19

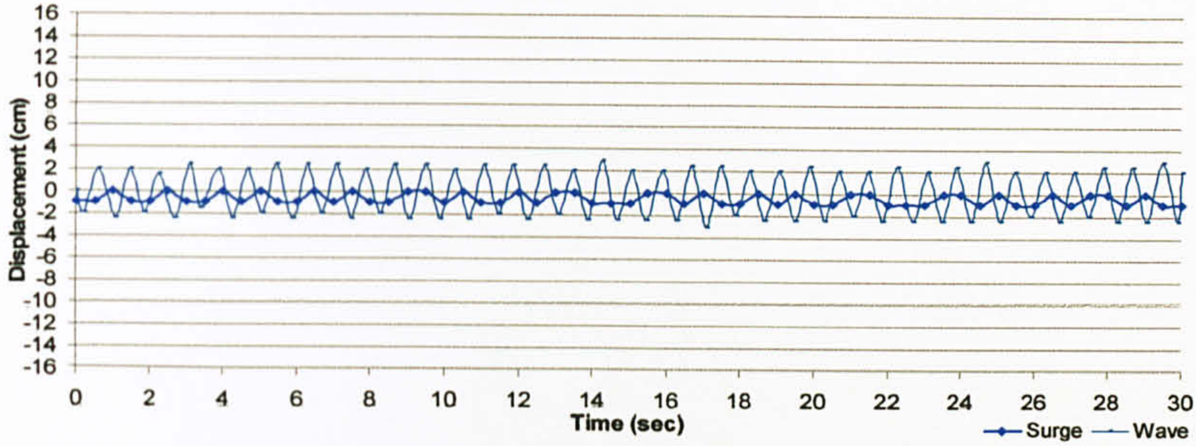

Figure 36a: Surge Response

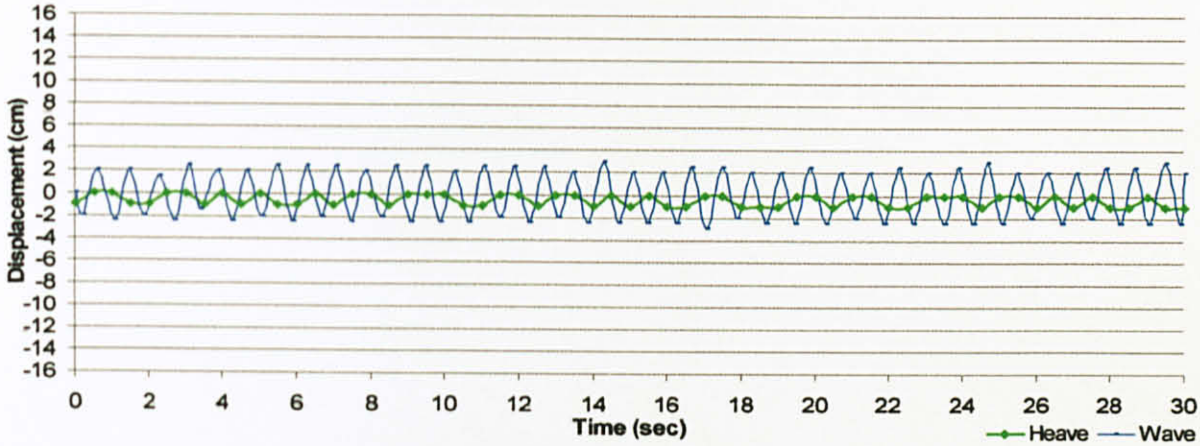

Figure 36b: Heave Response

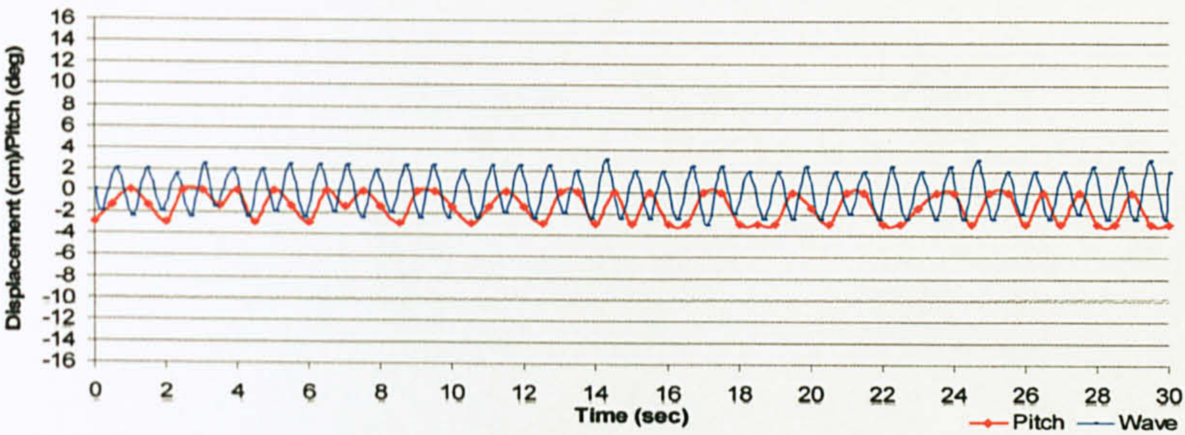

Figure 36c: Pitch Response

Figure 36 The Model Response in TEST 20

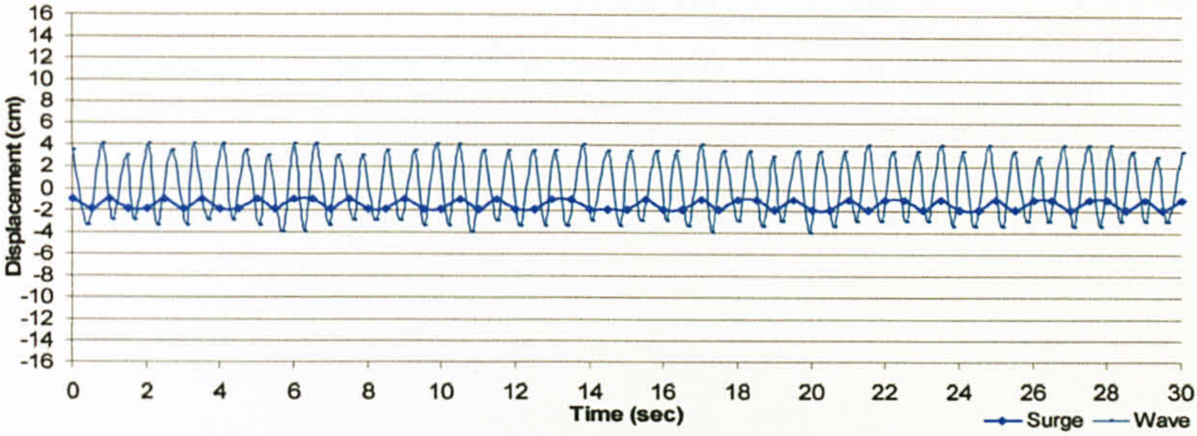

Figure 37a: Surge Response

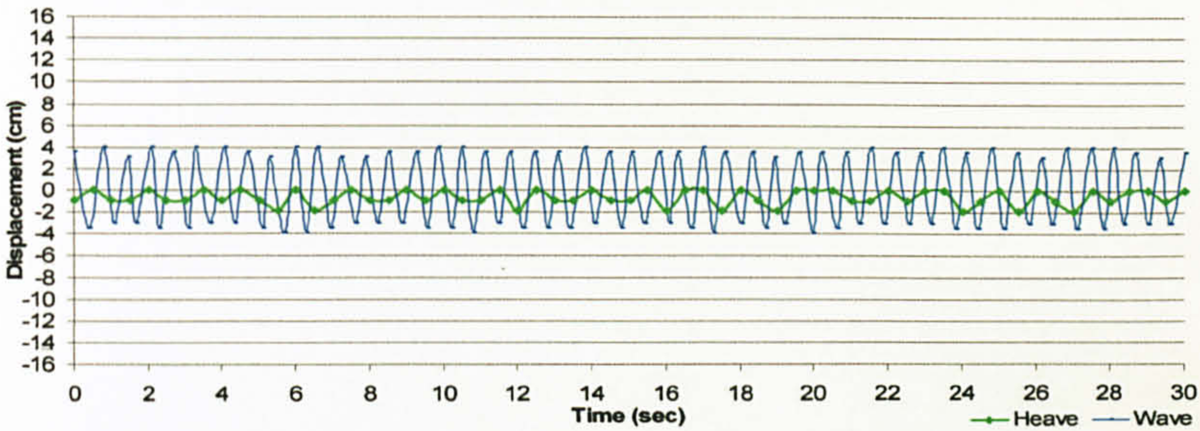

Figure 37b: Heave Response

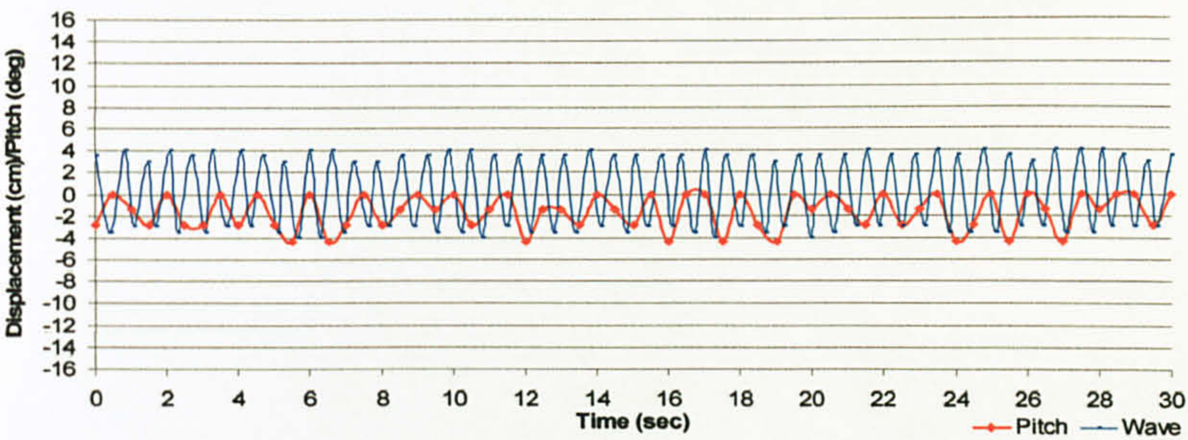

Figure 37c: Pitch Response

Figure 37 The Model Response in TEST 21

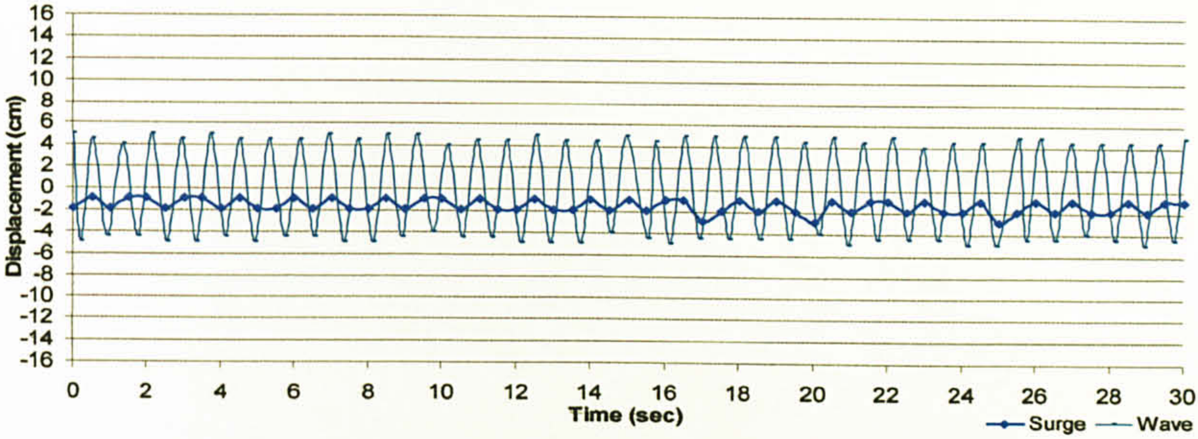

Figure 38a: Surge Response

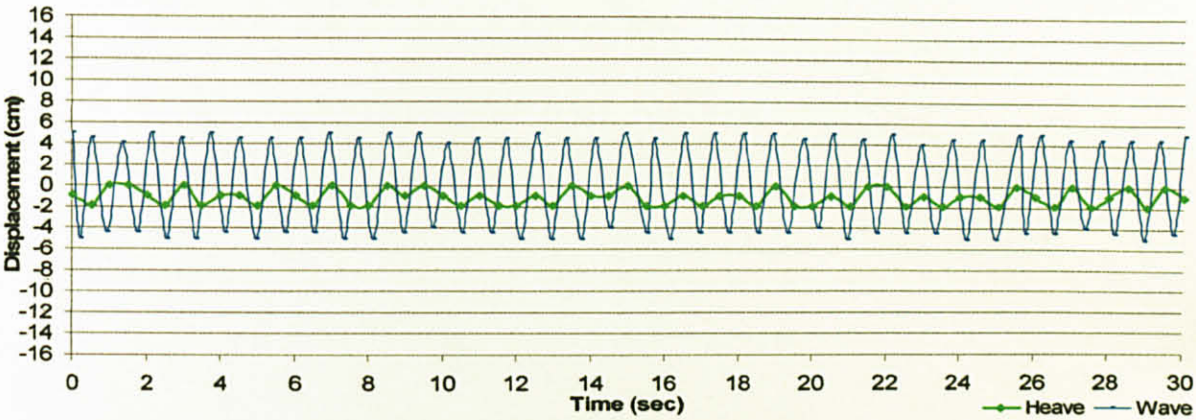

Figure 38b: Heave Response

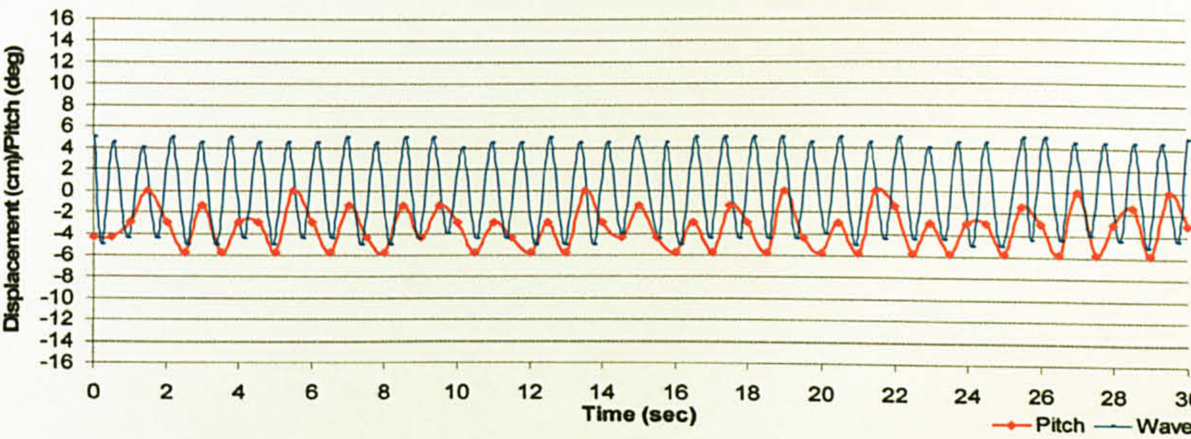

Figure 38c: Pitch Response

Figure 38 The Model Response in TEST 22

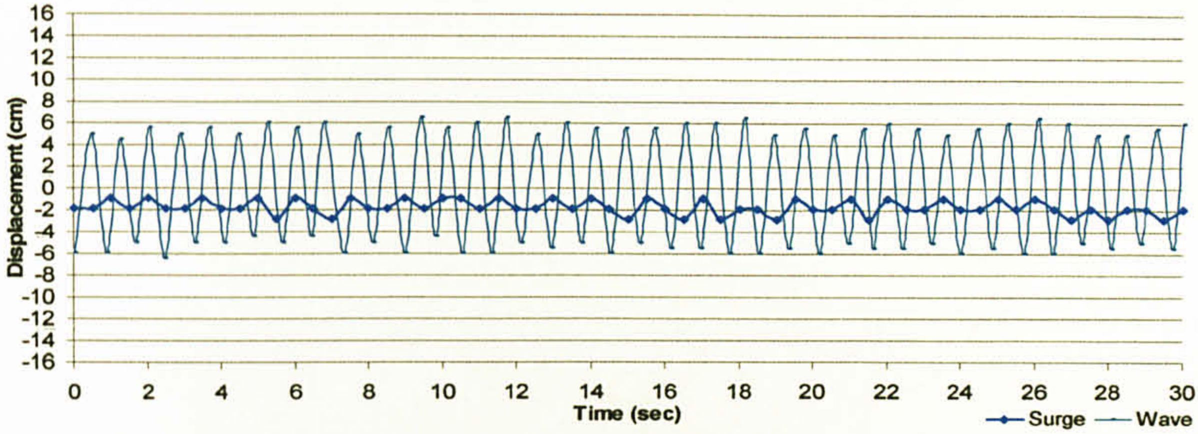

Figure 39a: Surge Response

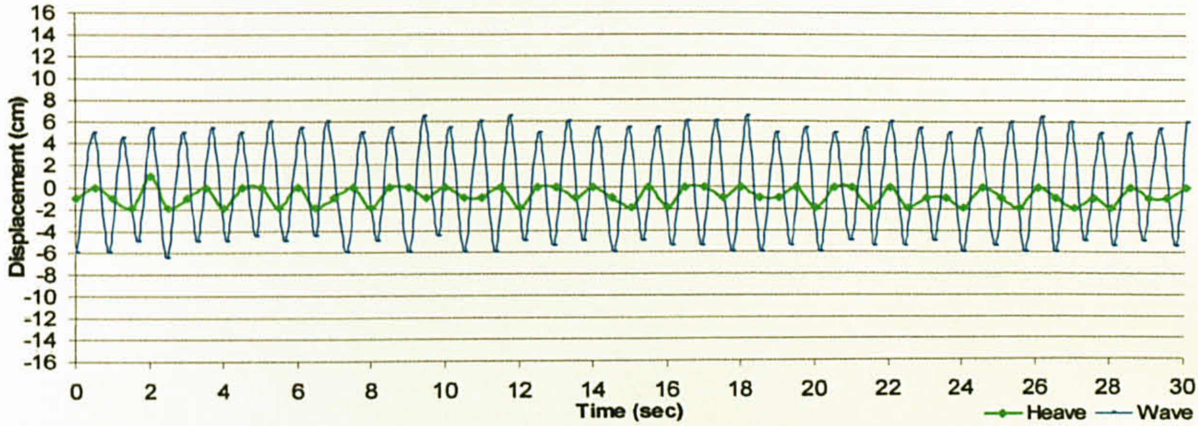

Figure 39b: Heave Response

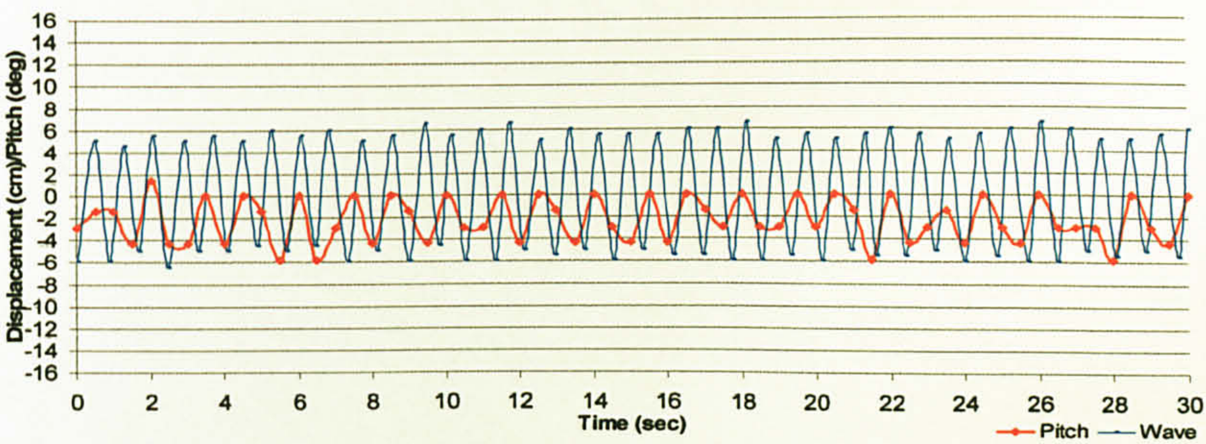

Figure 39c: Pitch Response

Figure 39 The Model Response in TEST 23

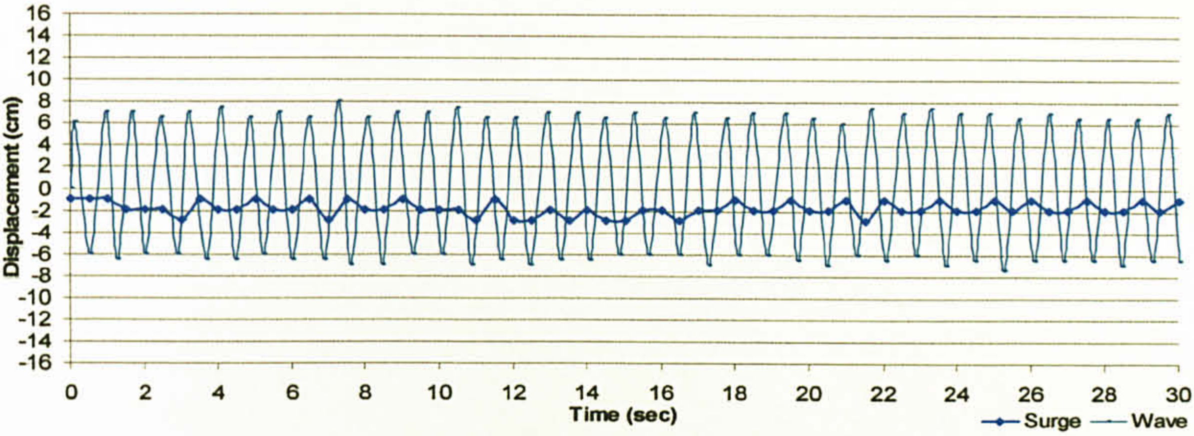

Figure 40a: Surge Response

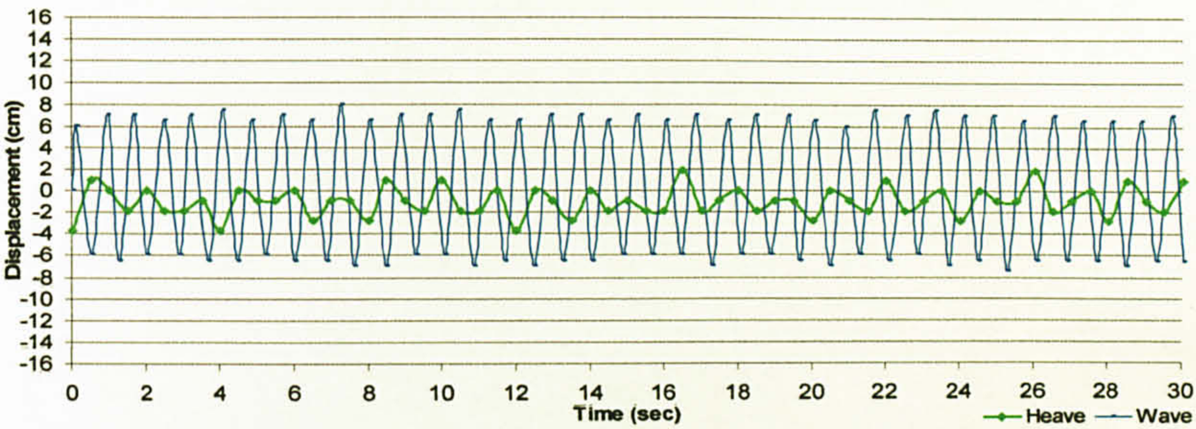

Figure 40b: Heave Response

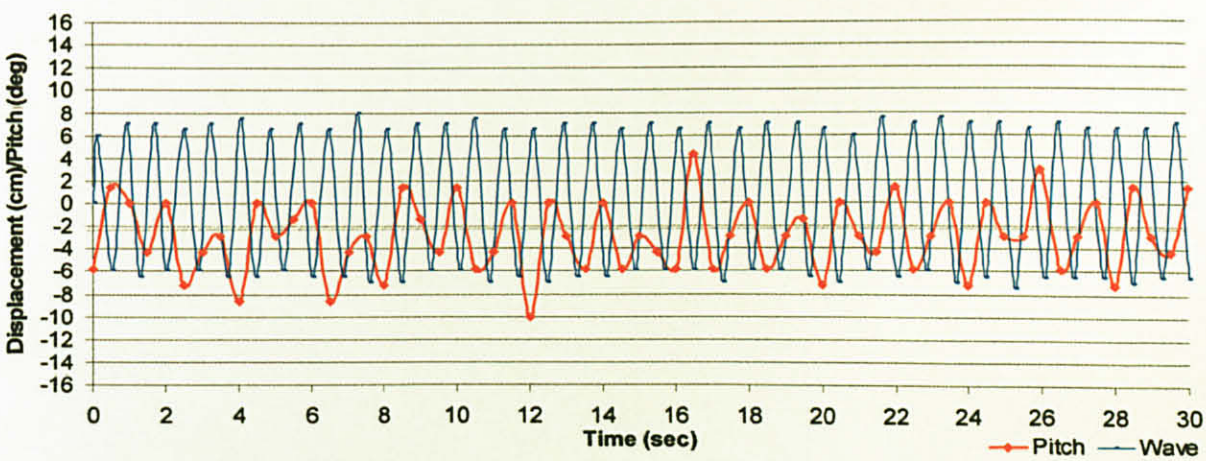

Figure 40c: Pitch Response

Figure 40 The Model Response in TEST 24

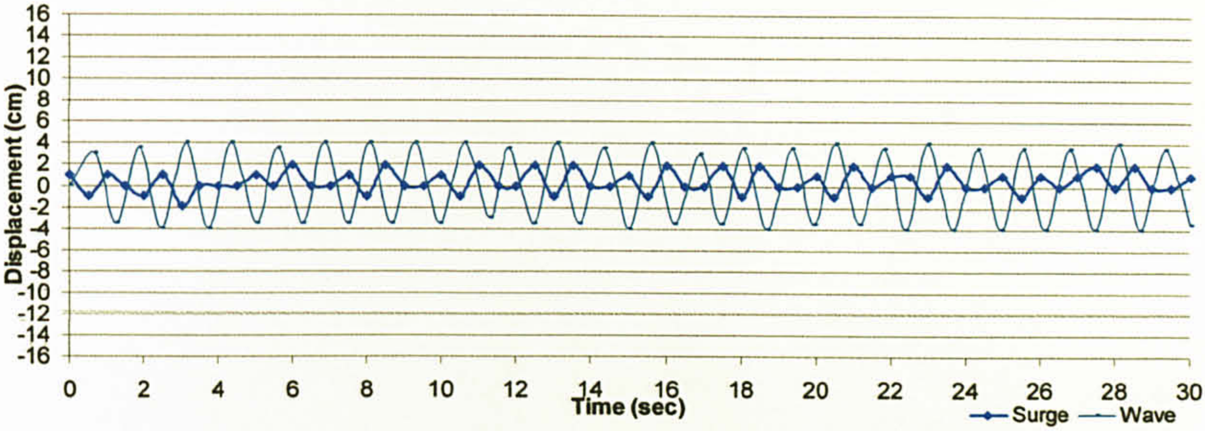

Figure 41a: Surge Response

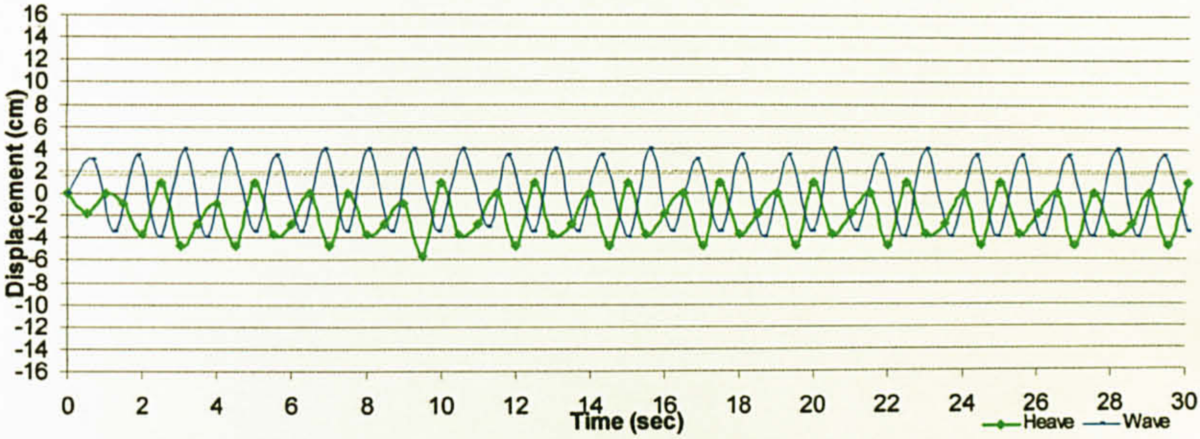

Figure 41b: Heave Response

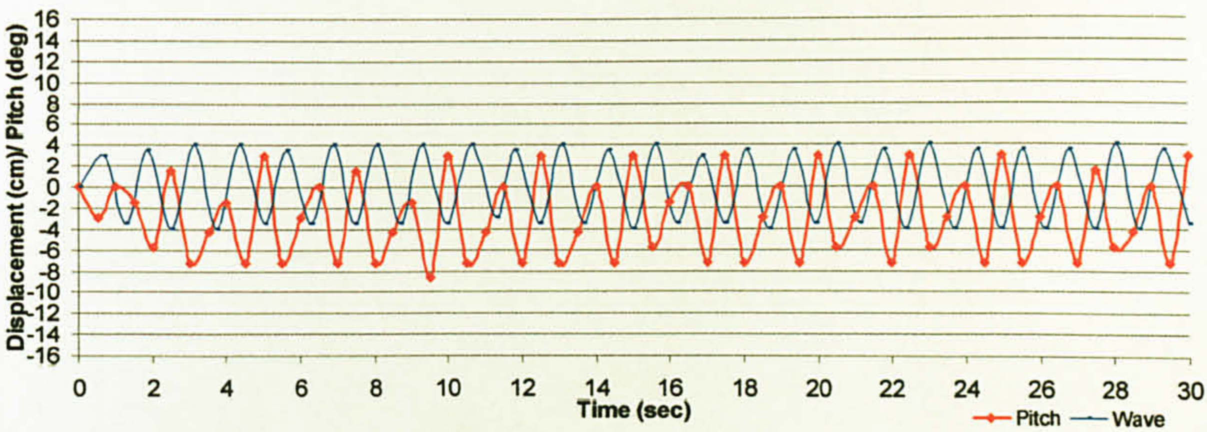

Figure 41c: Pitch Response

Figure 41 The Model Response in TEST 25

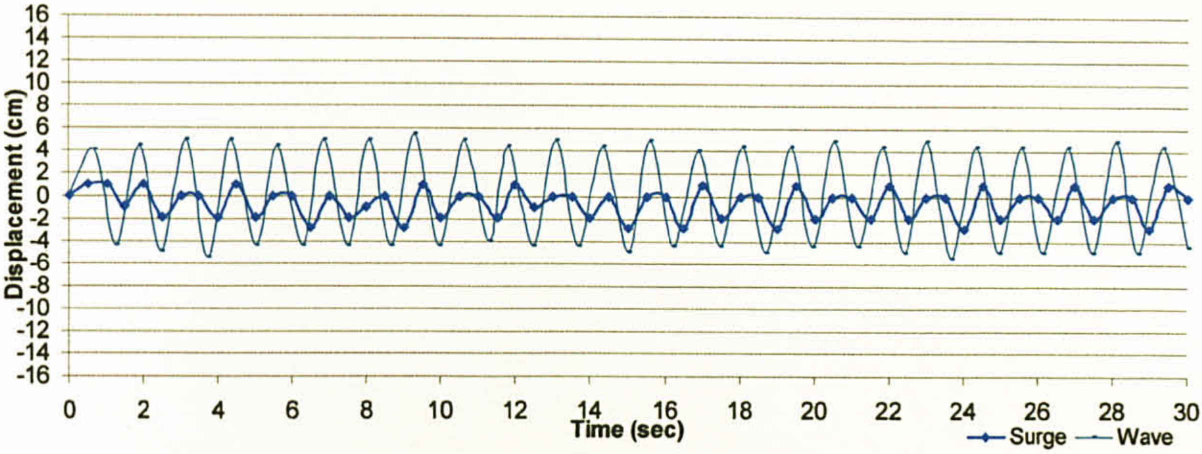

Figure 42a: Surge Response

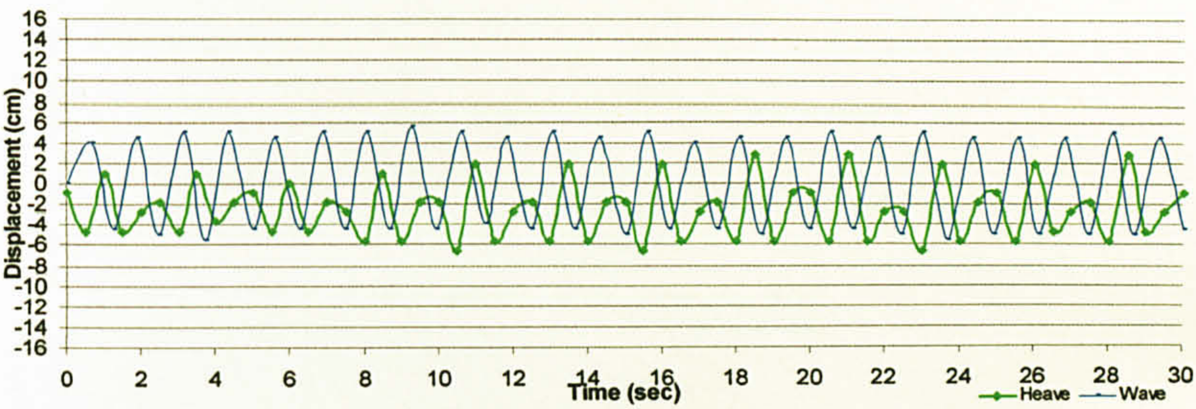

Figure 42b: Heave Response

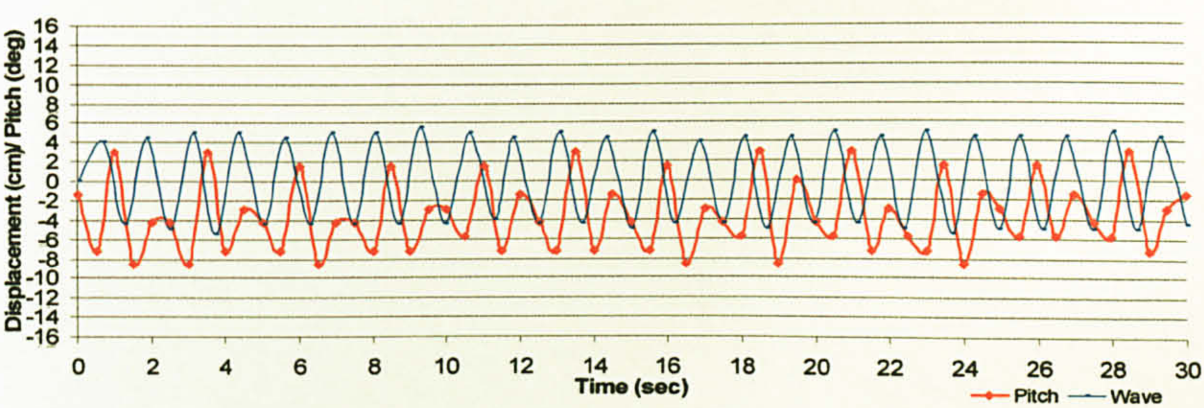

Figure 42c: Pitch Response

Figure 42 The Model Response in TEST 26

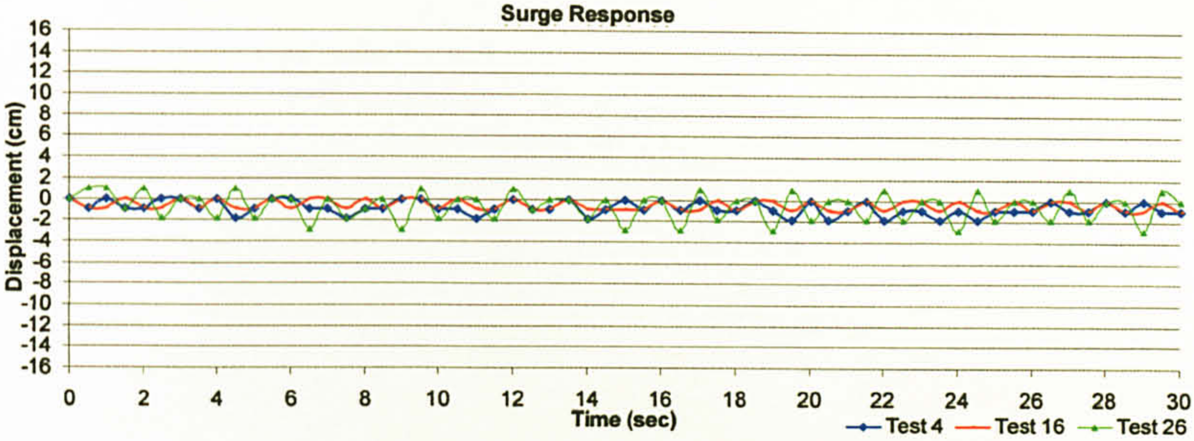

Figure 43a: Combined Surge Responses

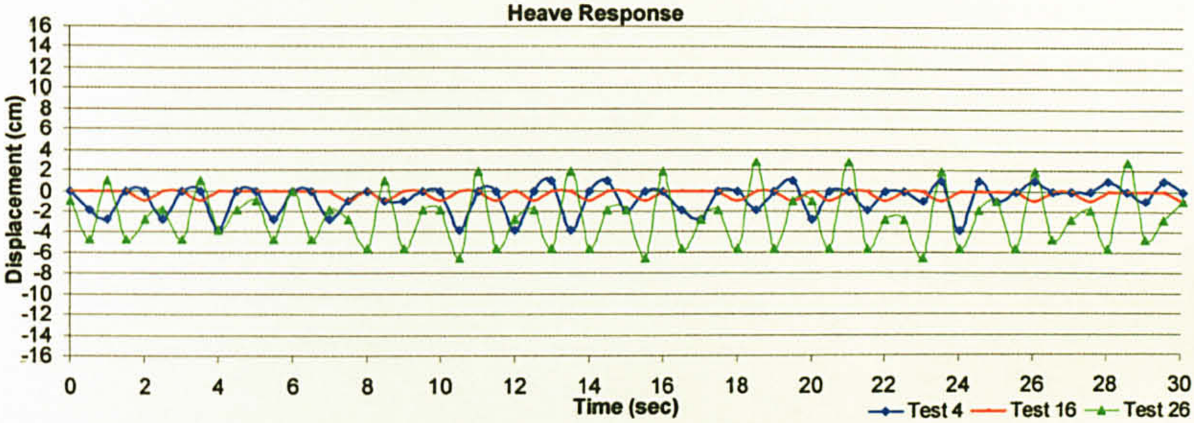

Figure 43b: Combined Heave Response

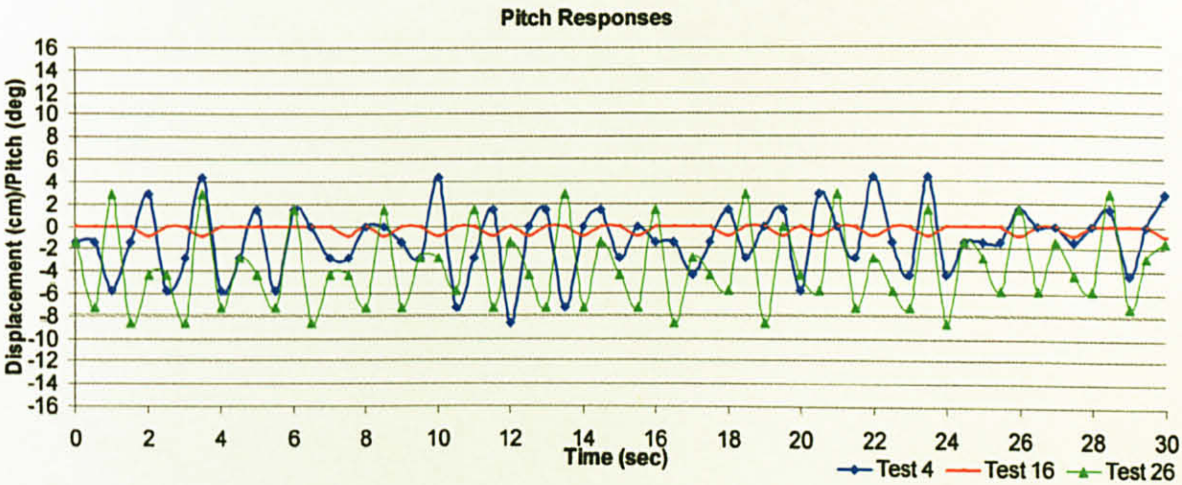

Figure 43c: Combined Pitch Response

Figure 43 The Combination of Surge, Heave and Pitch for TEST 4, 16 and 26

By looking at all Figure 43 above, it shows significant difference in the motions of the semi–submersible model in all three tests. Test 26 shows to have the largest motions in surge and heave, and Test 16 shows it has the smallest surge n heave. Pitch motion for Test 4 and 26 are almost the same and Test 16 shows to have the smallest pitch motion. Table 6 below will give a summary of results for the three simulations for the model and prototype. It should be noted that only surge and heave can transform between model and prototype by using a factor of $1/L_r$, L_r being the geometric length ratio, and pitch does not transform as it is non – dimensional.

Table 6 Comparative Summary of Tests Results

<table>
<tr><td></td><td colspan="2">Wave</td><td colspan="4">Maximum Heave</td><td colspan="4">Maximum Surge</td><td colspan="3">Maximum Pitch</td></tr>
<tr><td>Test</td><td>H (cm)</td><td>T(s)</td><td>+ve (cm)</td><td>-ve (cm)</td><td>Σ (cm)</td><td>% (1)</td><td>+ve (cm)</td><td>-ve (cm)</td><td>Σ (cm)</td><td>% (2)</td><td>+ve (o)</td><td>-ve (o)</td><td>Σ (o)</td></tr>
<tr><td>4</td><td>10</td><td>0.8</td><td>1</td><td>-3.8</td><td>4.8</td><td>9.8</td><td>0</td><td>-2</td><td>2</td><td>3.1</td><td>4.4</td><td>-5.8</td><td>10.2</td></tr>
<tr><td>16</td><td>10</td><td>0.8</td><td>0</td><td>-1</td><td>1</td><td>2</td><td>0</td><td>-1</td><td>1</td><td>1.5</td><td>0</td><td>-3</td><td>3</td></tr>
<tr><td>26</td><td>10</td><td>1.25</td><td>2.8</td><td>-6.6</td><td>9.4</td><td>18.8</td><td>1</td><td>-2.8</td><td>3.8</td><td>5.8</td><td>2.9</td><td>-8.7</td><td>11.6</td></tr>
<tr><td colspan="14">For the Prototype (real-life structure)</td></tr>
<tr><td>4</td><td colspan="2" rowspan="3">Corresponding Values for the prototype</td><td colspan="2" rowspan="3">Max heave displacement</td><td>5 m</td><td>"</td><td colspan="2" rowspan="3">Max surge displacement</td><td>2 m</td><td>"</td><td colspan="2" rowspan="3">Max pitch in degree</td><td>"</td></tr>
<tr><td>16</td><td>1 m</td><td>"</td><td>1 m</td><td>"</td><td>"</td></tr>
<tr><td>26</td><td>9 m</td><td>"</td><td>4 m</td><td>"</td><td>"</td></tr>
<tr><td colspan="14">(1) Relative to the total height of Semi - Submersible that is 49 cm for the model and 50 m for the prototype.
(2) Relative to the topside width that is 65 cm for the model and 67 m for the prototype
" denotes identical values</td></tr>
</table>

Most of the results in Table 6 above lie within acceptable practical ranges, expect perhaps for the maximum heave displacement for Test 26. It is uncertain whether the maximum heave of 9 m is acceptable in terms of operations. It is a large value and it is almost the same as the test wave height corresponds to the prototype that is 10 m.

From Table 6, the largest overall response belongs to Test 26 in terms of surge, heave and pitch. This test was associated with a longer wave period. The difference in all of its responses shows the importance of design wave period.

Comparing Test 4 and 16, a significance difference can be seen in all of the responses especially pitch response. The actual difference in these two cases is the total weight.

The model in test 16 is lighter by 33% than the one in Test 4. The difference in weight has led to a better performance in all responses especially the pitch response.

Compare all of the responses of the three tests with the design values given in Chapter 3; there is a big difference between experimental data and design values. Test 26 which has a similar wave period to the design value actually gave a larger pitch response. The design maximum pitch was +/- 4° for return period of 10-years and +/- 10° for a return period of 100-years. The pitch response of 11.2° has already exceeded maximum pitch for both 10 and 100 years return period. This actually shows that the actual response of a floating structure will not be as what it is predicted.

One reason is because of the changing wave characteristics. In the open sea, the wave conditions are always changing and it will not be the same every time. So no matter how a wave is scaled down for a test or analysis, its characteristics will not be the same as the actual wave. The wave shapes are always changing and so all of its characteristics and the wave force. There is yet a solid way of scaling down a wave and get a similar effect with the actual one. Even with the correct scaling down of the wave heights and periods, the wave action will not be the same as the one in actual. So that is why there is difference in the computer generated design values and also the experimental data obtained. In the future, anyone who wants to do any tests or analysis on the response of a floating structure would need to really take into consideration about scaling down the wave.

4.2.2 Random Wave Test

According to Table 3, there would be five runs of random wave tests with a range of 3-12 cm wave heights and with a maximum loading condition. The random wave tests were also done in the wave basin with the same model setup. The wave paddle can produce random waves based on three types of wave spectrum; JONSWAP, P.M., and Moskovitz spectrum. JONSWAP spectrum was chosen for all five tests as it can include the wave heights and wave period. Cameras from the side will record the motion response of the semi–submersible model due to wave and data will be extracted.

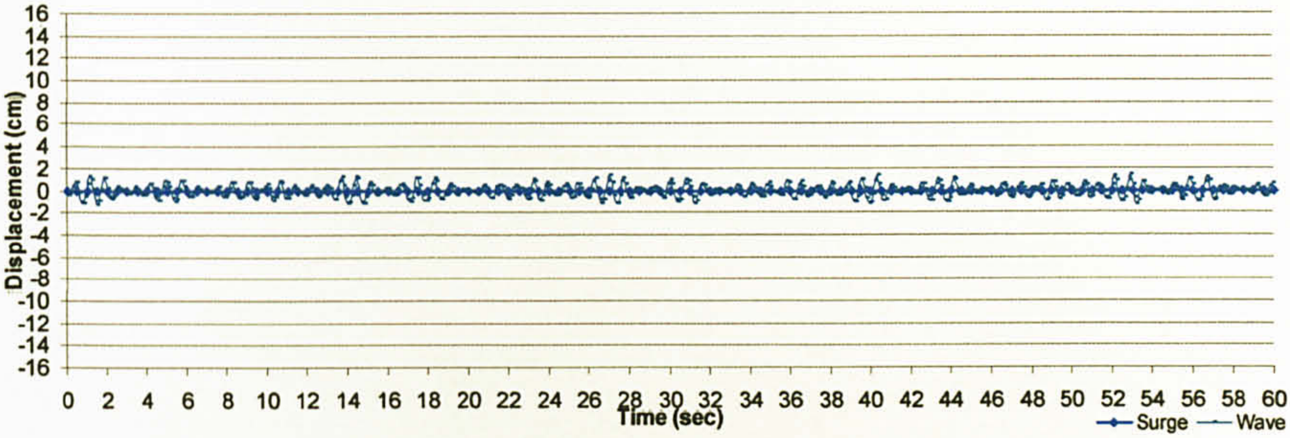

Figure 44a: Surge Response

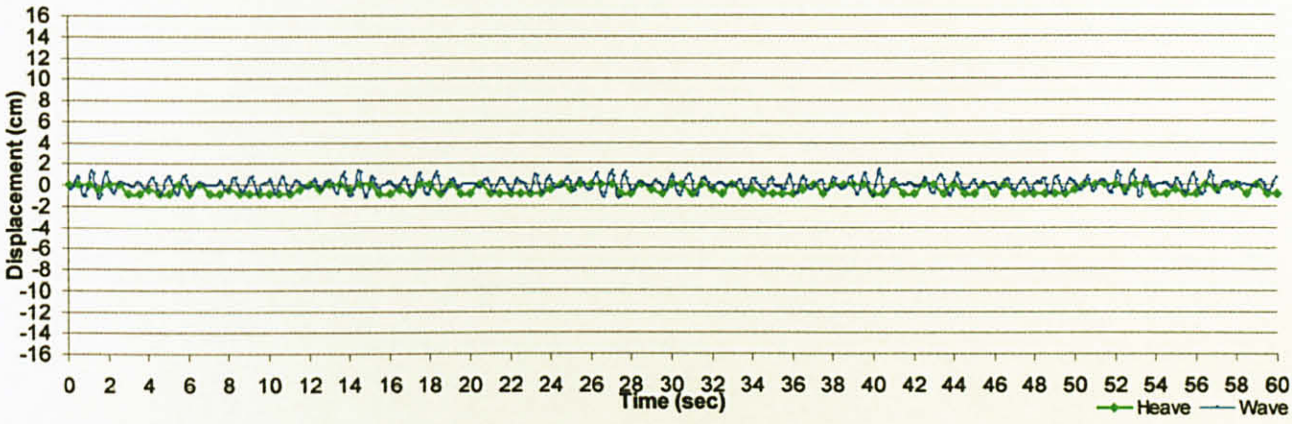

Figure 44b: Heave Response

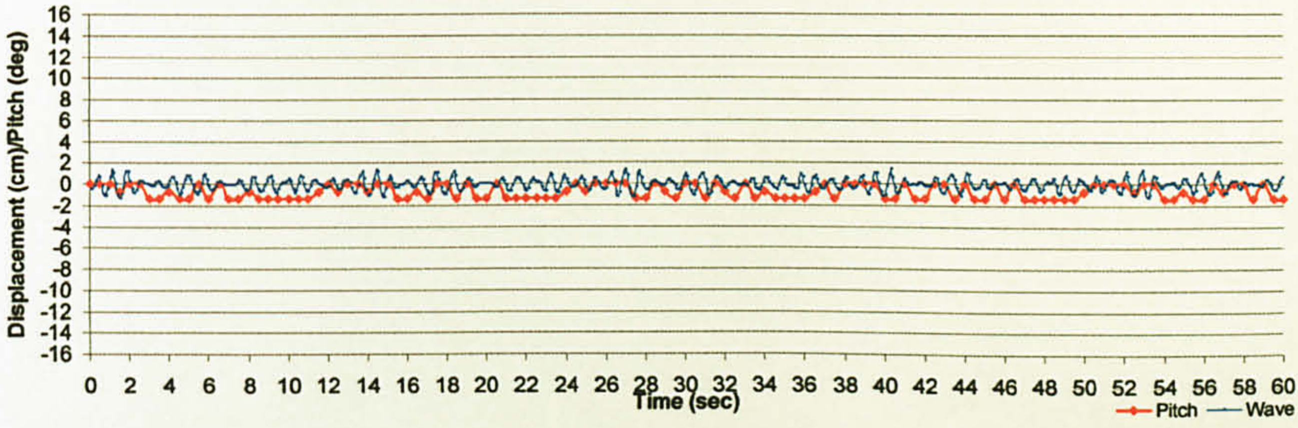

Figure 44c: Pitch Response

Figure 44 The Model Response in TEST 27

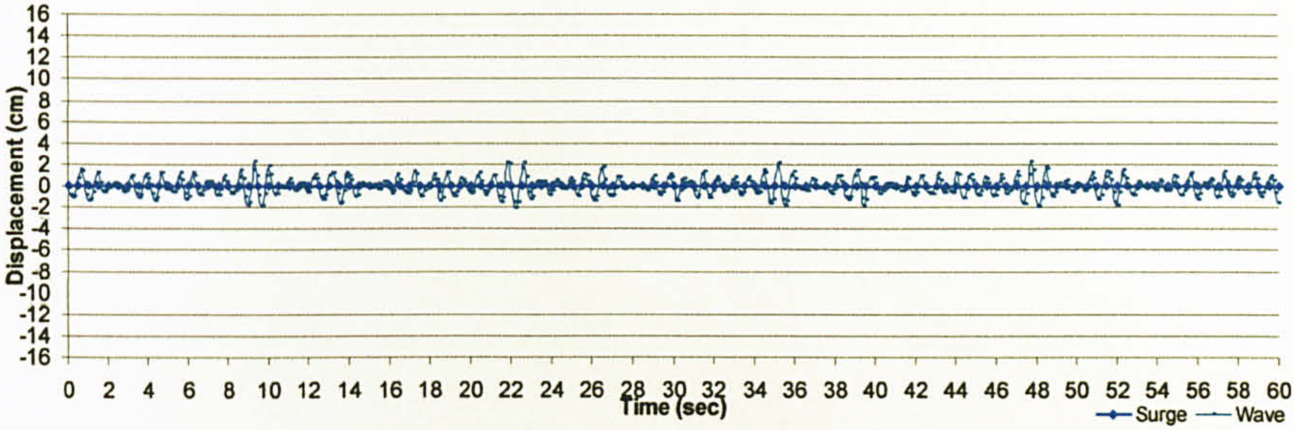

Figure 45a: Surge Response

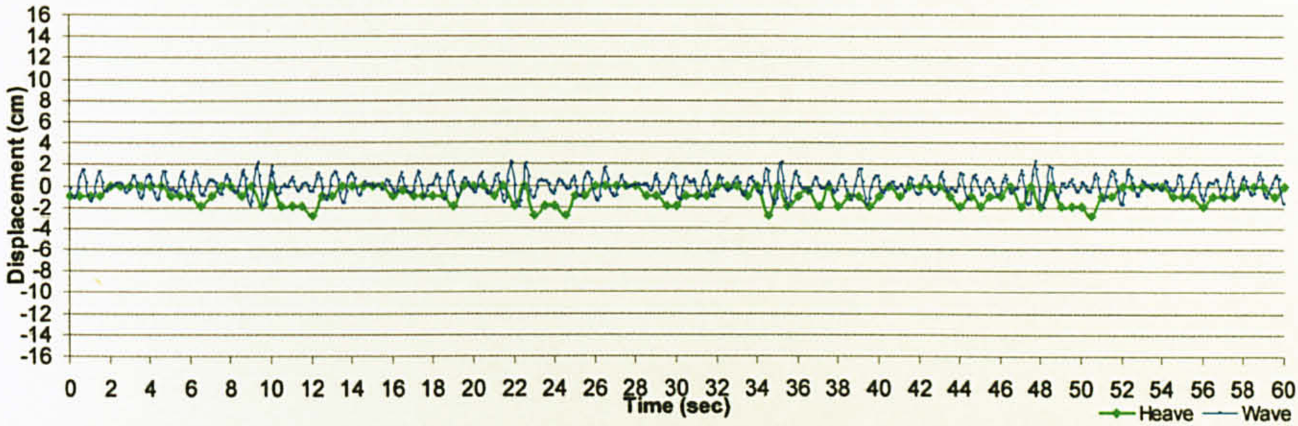

Figure 45b: Heave Response

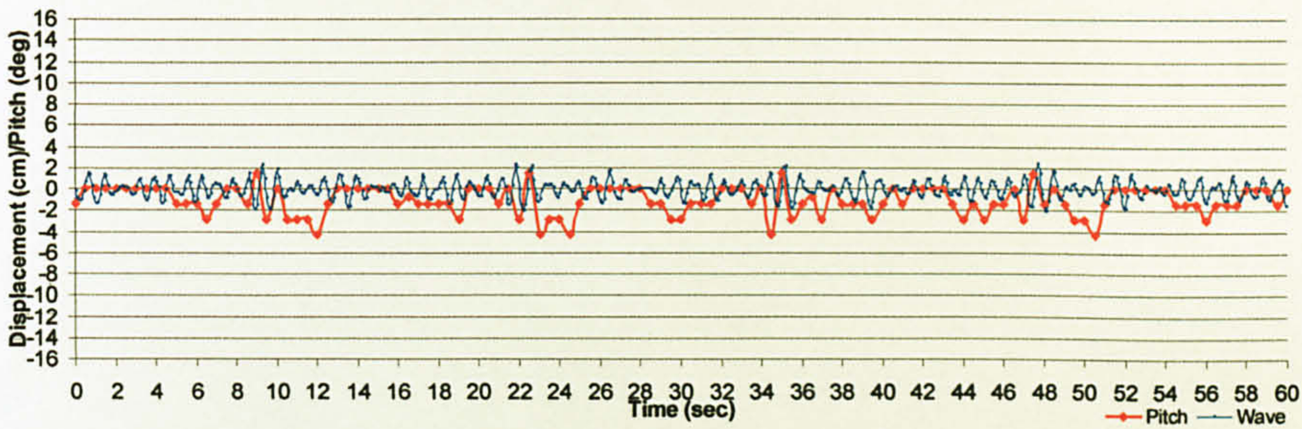

Figure 45c: Pitch Response

Figure 45 The Model Response in TEST 28

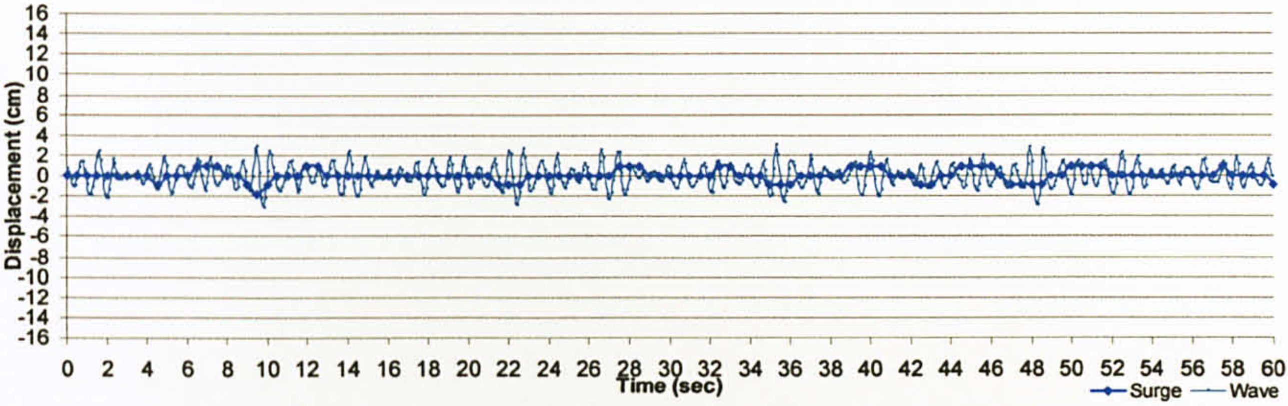

Figure 46a: Surge Response

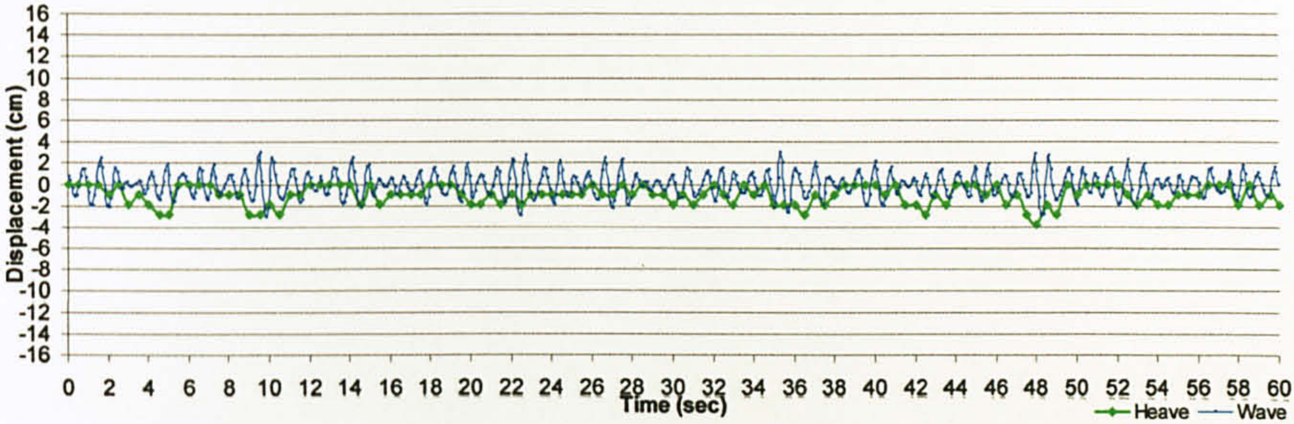

Figure 46b: Heave Response

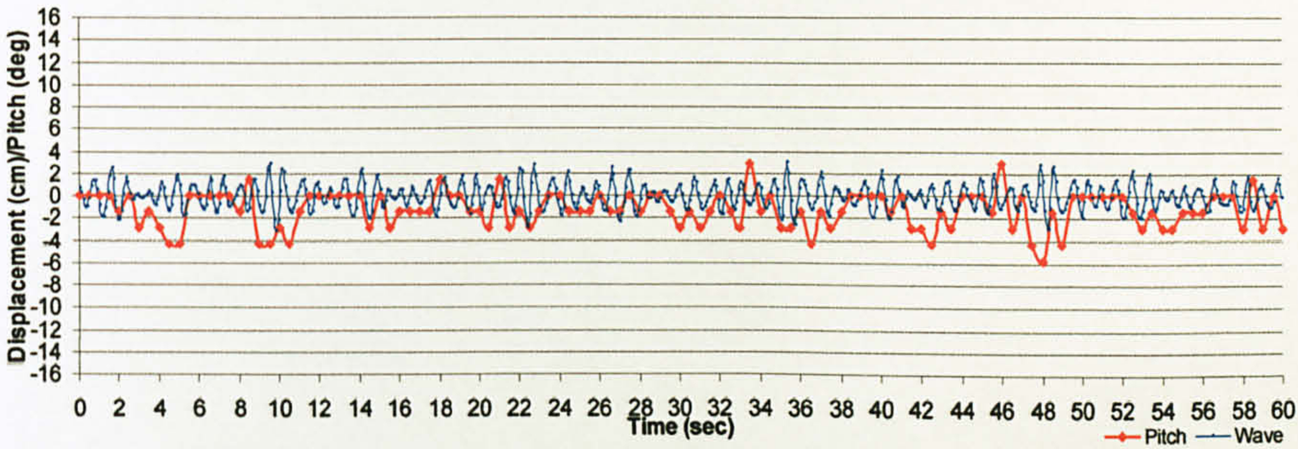

Figure 46c: Pitch Response

Figure 46 The Model Response in TEST 29

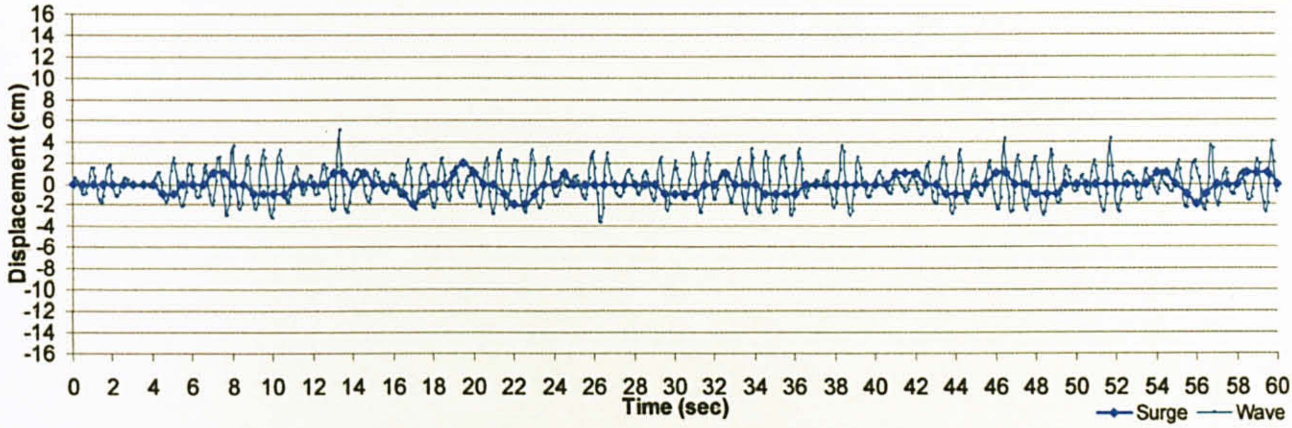

Figure 47a: Surge Response

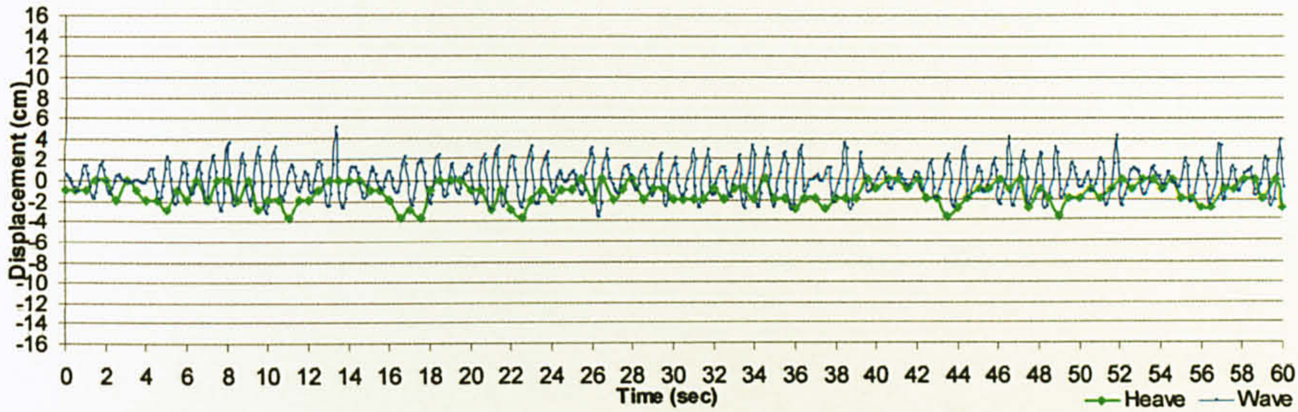

Figure 47b: Heave Response

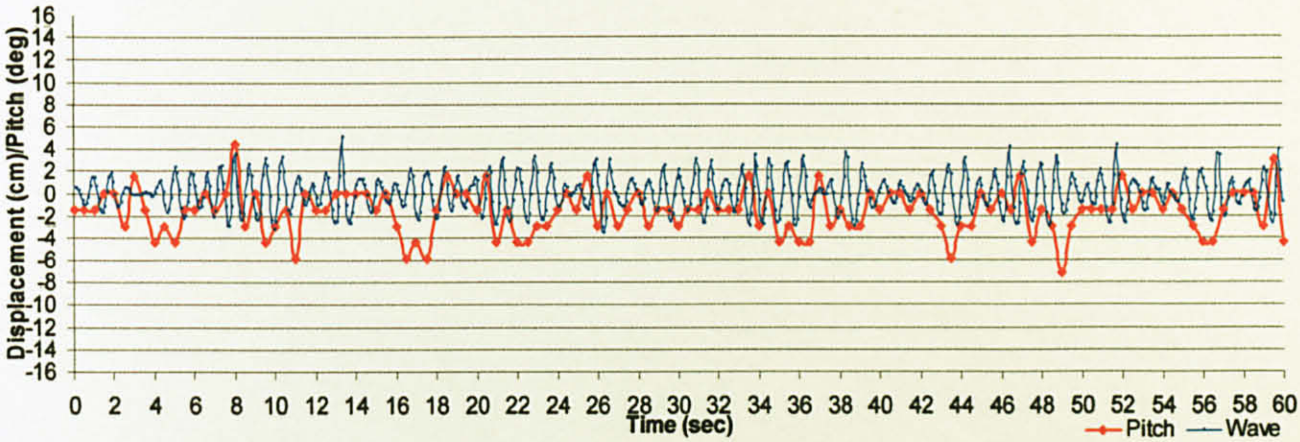

Figure 47c: Pitch Response

Figure 47 The Model Response in TEST 30

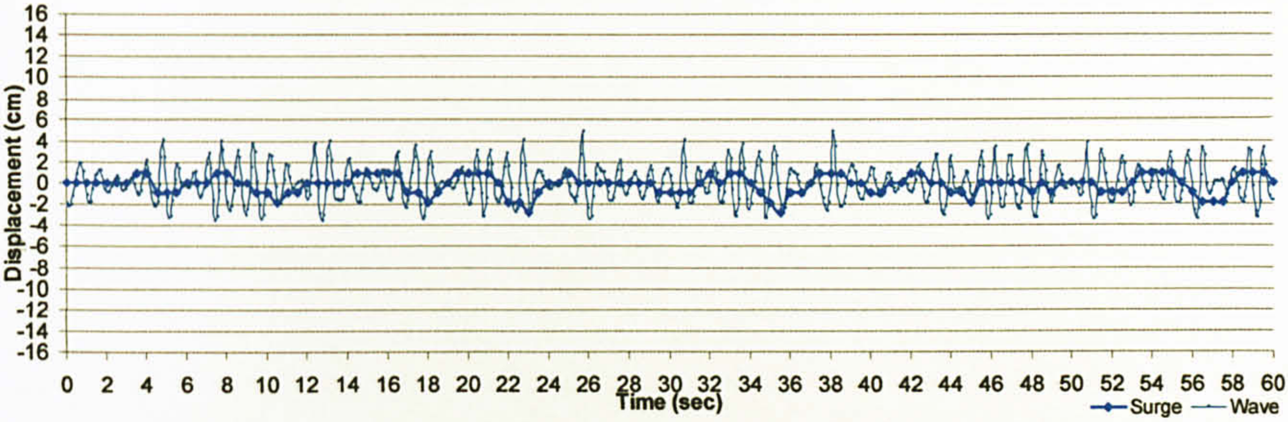

Figure 48a: Surge Response

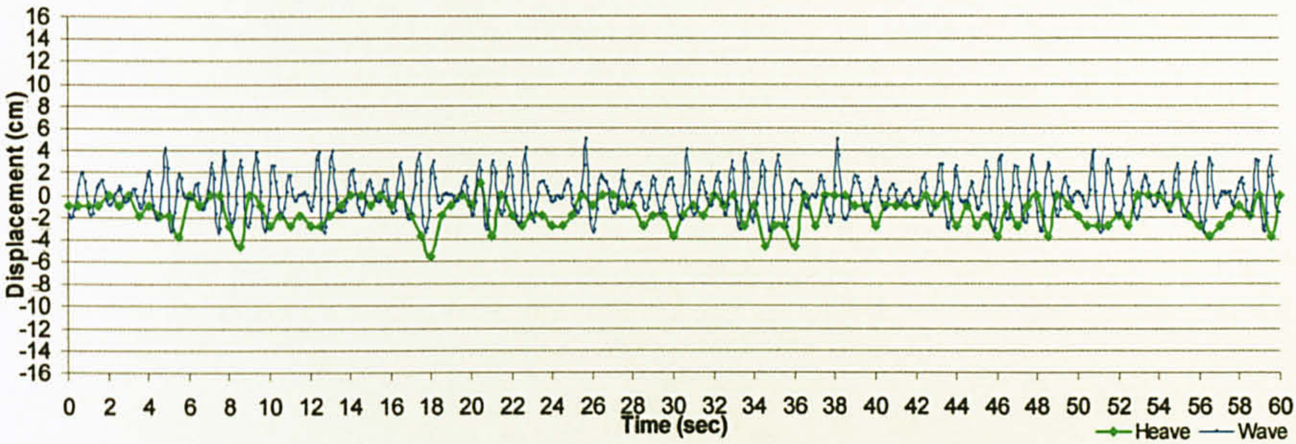

Figure 48b: Heave Response

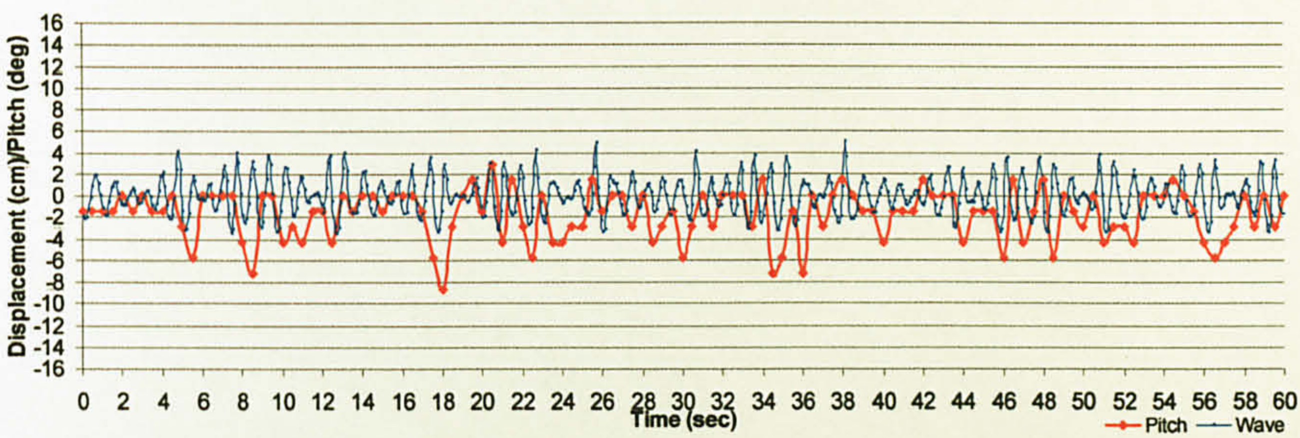

Figure 48c: Pitch Response

Figure 48 The Model Response in TEST 31

Based on Table 3, from five tests that were completed; only Test 30 will be reported here. The data of the test will be included in the Appendix.

Comparing the graphs on Figure 47 and the graphs from Figure 20 shows a difference in the response of all three surge, heave and pitch motions.

Table 7 Comparative Summary of Test 4 and Test 30

<table>
<tr><th></th><th colspan="2">Wave</th><th colspan="4">Maximum Heave</th><th colspan="4">Maximum Surge</th><th colspan="3">Maximum Pitch</th></tr>
<tr><th>Test</th><th>H (cm)</th><th>T(s)</th><th>+ve (cm)</th><th>-ve (cm)</th><th>Σ (cm)</th><th>% (1)</th><th>+ve (cm)</th><th>-ve (cm)</th><th>Σ (cm)</th><th>% (2)</th><th>+ve (o)</th><th>-ve (o)</th><th>Σ (o)</th></tr>
<tr><td>4</td><td>10</td><td>0.8</td><td>1</td><td>-3.8</td><td>4.8</td><td>9.8</td><td>0</td><td>-2</td><td>2</td><td>3.1</td><td>4.4</td><td>-5.8</td><td>10.2</td></tr>
<tr><td>30</td><td>10</td><td>0.8</td><td>0</td><td>-3.8</td><td>3.8</td><td>7.8</td><td>1.9</td><td>-1.9</td><td>4</td><td>6.2</td><td>4.4</td><td>-7.2</td><td>11.6</td></tr>
<tr><td colspan="14">For the Prototype (real-life structure)</td></tr>
<tr><td>4</td><td colspan="2" rowspan="2">Corresponding Values for the prototype</td><td colspan="2" rowspan="2">Max heave displacement</td><td>5 m</td><td>“</td><td colspan="2" rowspan="2">Max surge displacement</td><td>2 m</td><td>“</td><td colspan="2" rowspan="2">Max pitch in degree</td><td>“</td></tr>
<tr><td>30</td><td>5 m</td><td>“</td><td>4 m</td><td>“</td><td>“</td></tr>
<tr><td colspan="14">(1) Relative to the total height of Semi - Submersible that is 49 cm for the model and 50 m for the prototype.
(2) Relative to the topside width that is 65 cm for the model and 67 m for the prototype
“ denotes identical values</td></tr>
</table>

From Table 7, it shows that the motion responses in random waves are of no difference from motion due to regular waves. The only slight difference is in the maximum surge and pitch motion between both tests. So the motion response of the model is not influenced by the type of waves. It will only be influence by the wave heights and periods.

4.3 Damping Test

The damping test was done to obtain equations of motion that would predict the response of heave motions of a semi–submersible platform due to waves. From this test also the damping coefficient, C and natural frequency, ω_n of the semi-submersible model can be obtained. As per stated in Chapter 3, the test was conducted based exactly on Figure 13. The model was pushed down into the water and later released. The oscillation of the semi-submersible model is recorded and the video is analyzed.

Data of the heave damping test was extracted and the results are shown in Table 8.

Table 8 Result of Damping Oscillation

Time (s)	Heave (cm)
0.00	-26
0.13	-22
0.26	-17
0.39	-12
0.52	-6
0.65	-1
0.78	5
0.91	3.5
1.04	0
1.17	-1
1.30	-2
1.43	-2.5

Time (s)	Heave (cm)
1.56	-1.5
1.69	-0.5
1.82	0
1.95	1
2.08	0.5
2.21	0
2.34	0
2.47	0
2.60	0
2.73	0
2.86	0
2.99	0

From the results above, a graph was plotted to show the decaying displacement of the model against time.

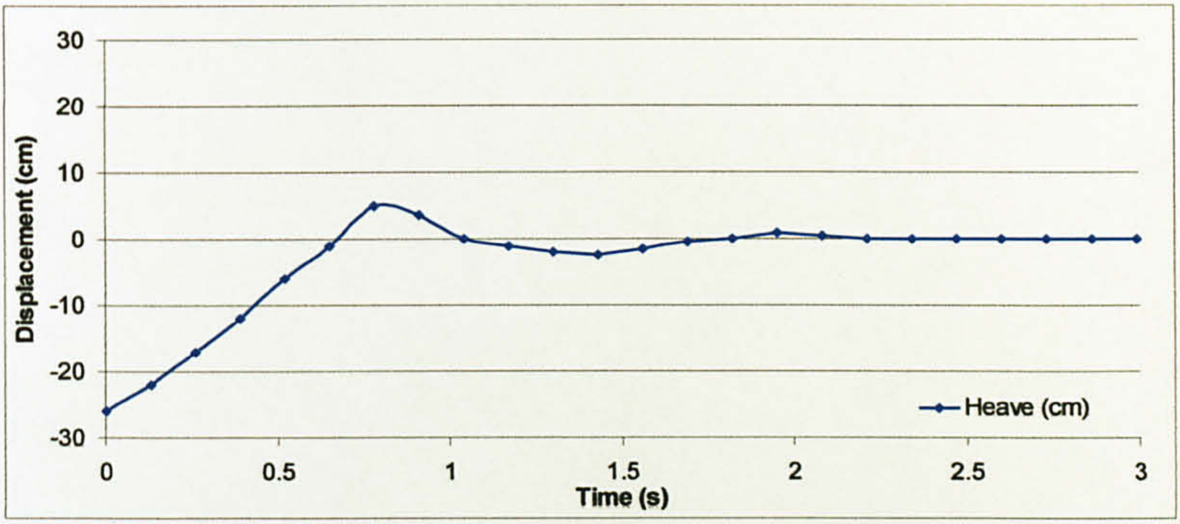

Figure 49 Graph of Damping vs Time

The graph starts at negative as it is initially pushed down in the water and then it was released to see it oscillates in the water. That is why the graph starts from negative and then it starts to be positive. From the graph above, the peaks can form an exponential trend line as below.

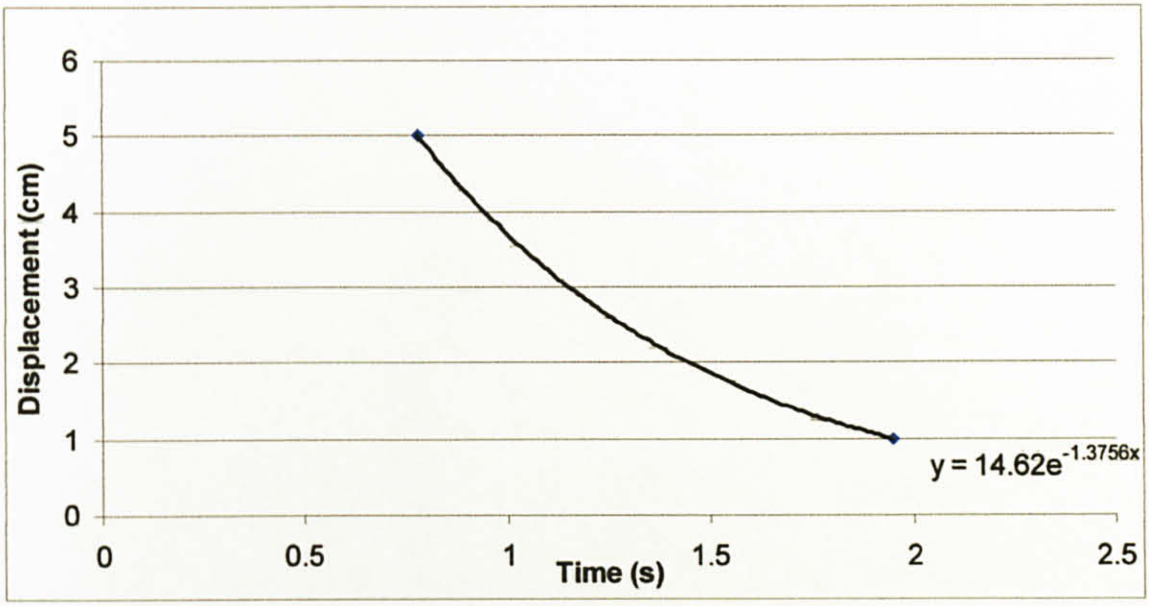

Figure 50 Exponential Trend Line

An exponential equation was form from the trend line above. The equation is:

$$y = 14.62e^{-1.3756x} \quad (8)$$

Below are the calculations to get the EOM for heave motion.

Equation (8) above is equal to $y = Xe^{-\xi\omega nt}$

Damping, C value can be calculated from ξ. So the equation above needs to be solved.

$\omega_n = (K/m)$^$(1/2)$

Where,

K = Stiffness = γA (density of water x water plane area of structure)

M = mass of structure = 52.6 kg

γ = 1000 kg/m³

$A = (0.15 \times 0.15 \times 4) = 0.09\ m^2$

Thus,

$K = 1000 \times 0.09 = 90$ kg/m

With the value of stiffness obtained, natural frequency can be calculated

$\omega_n = (90/\ 52.6)$^(1/2) = 1.31 Hz

$e^{-1.3756} = e^{-\xi\omega n}$

$e^{-1.3756} = e^{-\xi(1.31)}$

Thus damping factor is as below:

$\xi = 0.95$

The damping factor, ξ is 0.95 (<1), so it is nearing critical damping and it shows in the damping test, where the structure only fluctuates once.

Damping coefficient is,

$C = \xi \times C_c$

$C_c = 2 \times (K \times m)$^(1/2)

$= 2 \times (90 \times 52.6)$^(1/2)

$= 137.61$

Thus,

$C = 0.95 \times 137.61 = 130.73$

With all the coefficient needed calculated, thus equation of motion is as below,

$Mx'' + Cx' + Kx = F(t)$

$52.6x'' + 130.73x' + 90x = F(t) = 0$

With this equation, it can be used to compare with all the analysis calculations that were already done by other researchers before. This equation will also help in the analysis to predict a heave response for a semi–submersible platform in the future.

4.4 Force Test

A total of 4 Tests with 3 runs for each test was conducted. Based on Table 4, from chapter 3, it shows the condition of all 12 runs. The runs will alternate starting with only having current, then wave and current together and lastly wave only. The force from wave and current towards the semi-submersible model will be shown on the weight scale. All videos recording the weight scale reading have been analyzed.. Wave fluctuations and current velocity are recorded by wave probes and current meter in the wave basin. Results of all force tests are shown in Figure 51 to 54 below.

One of the problem occur, the weight scale is giving a negative reading of the force while the model are being tested. It was found out that, there was an equipment defect with the weight scale. When it is being at an angle, the can be pushed back due to inertia from the wave and current forces, so it gives a negative reading. So it was decided that all negative readings will not be considered and it will be considered as zero.

Results of the force calibration can later be used to compare theoretical calculations of wave force with the actual values. The result from this test can be compared with Froude-Krylov theory for calculation of wave force. There was no calculation done to prove the comparison between the result and Froude-Kyrlov theory as it was stated earlier that this research is based on experimental study of the semi-submersible model towards wave. So the data from this wave tests can later be applied by other researchers to compare it with any theoretical calculations such as Froude-Krylov theory.

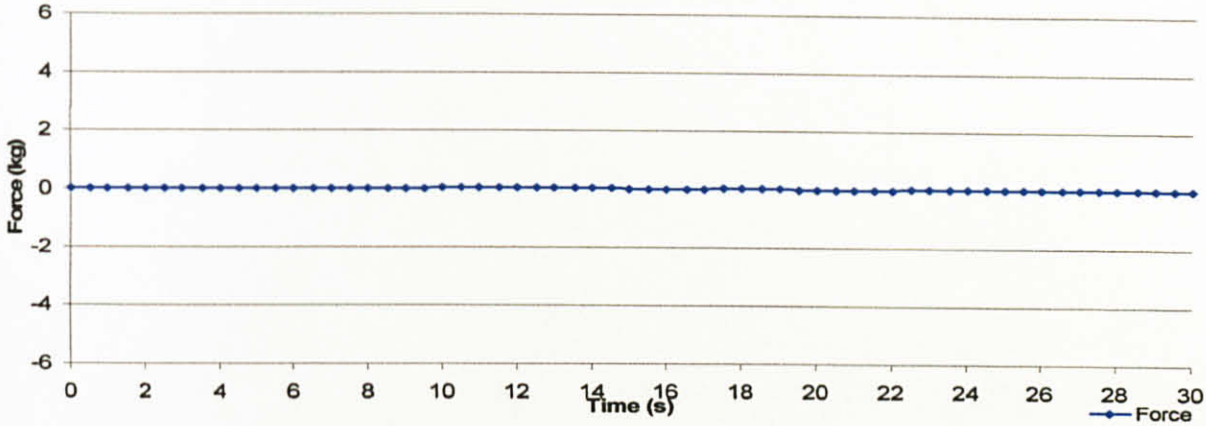

Figure 51a: Force Test Run 1

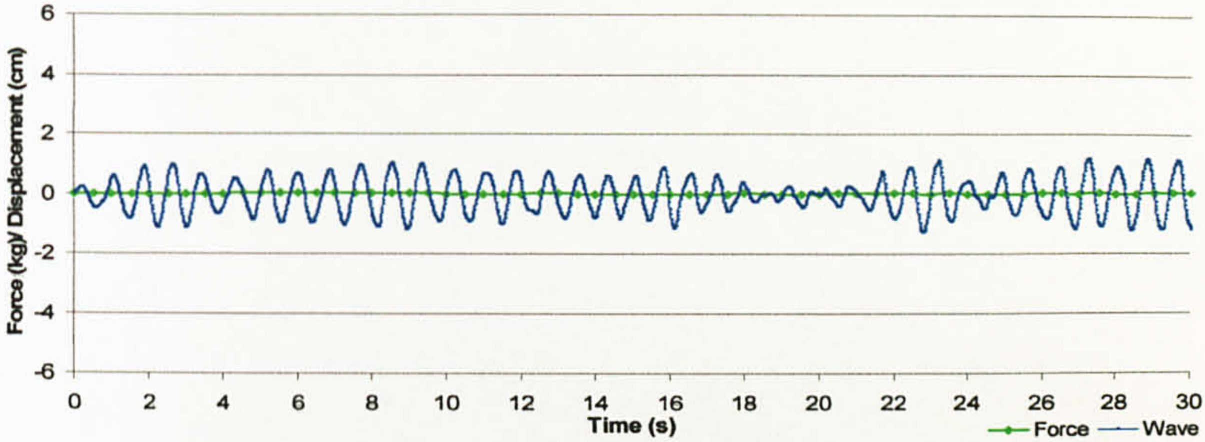

Figure 51b: Force Test Run 2

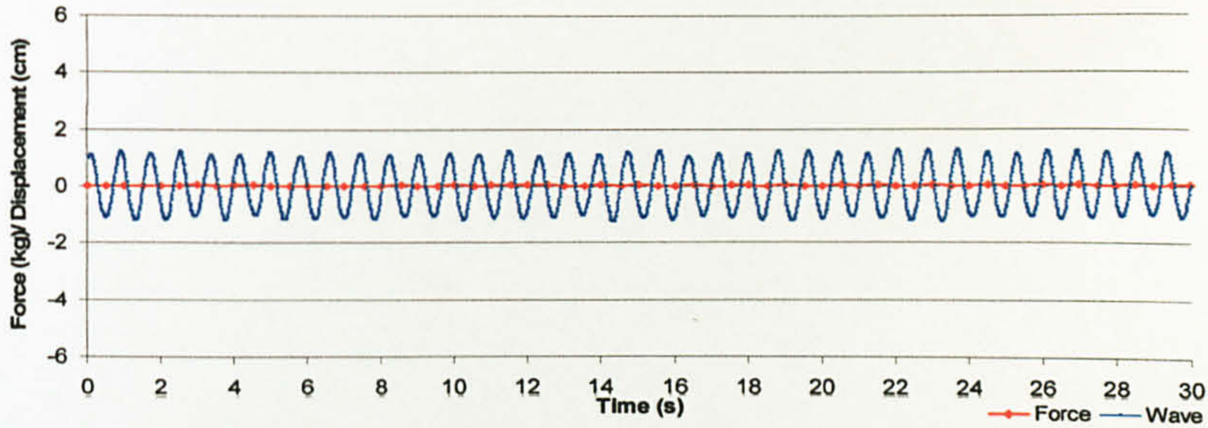

Figure 51c: Force Test Run 3

Figure 51 Force Test 1

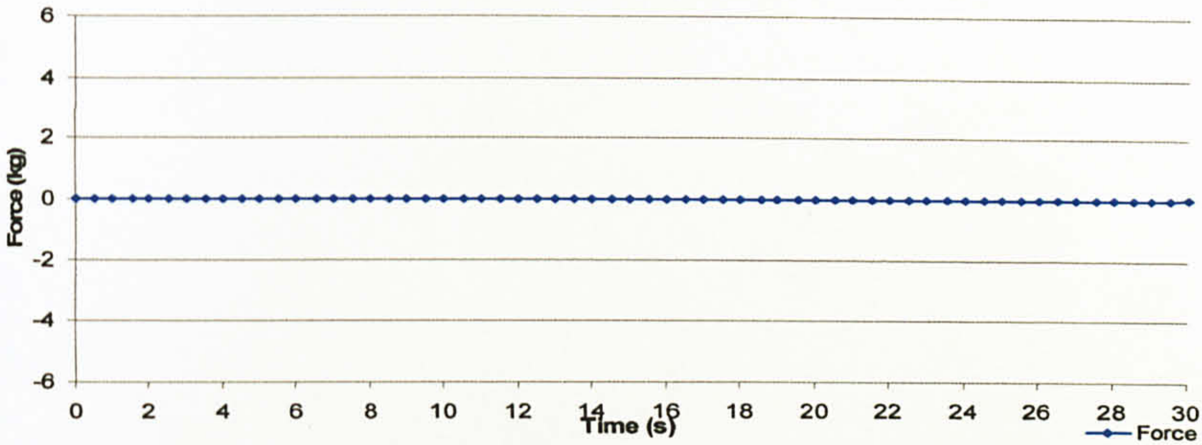

Figure 52a: Force Test Run 4

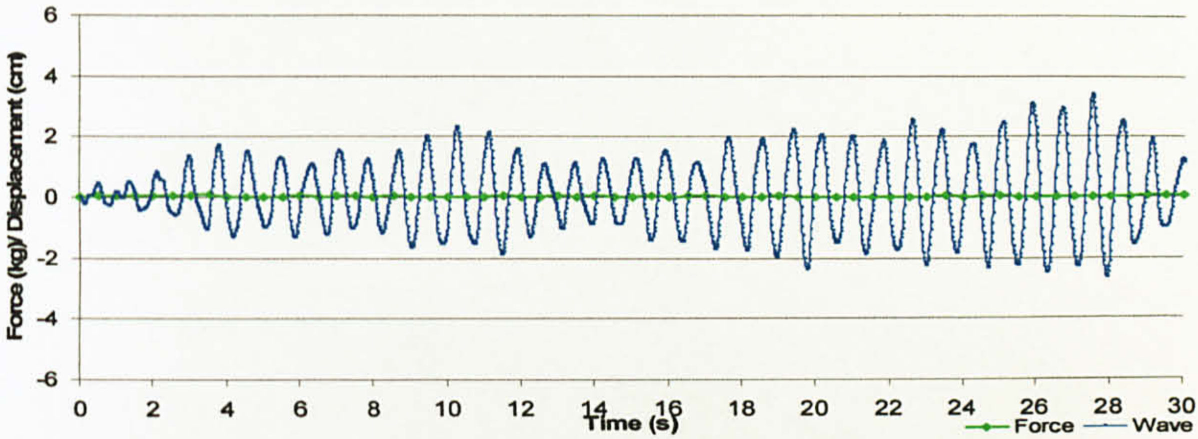

Figure 52b: Force Test Run 5

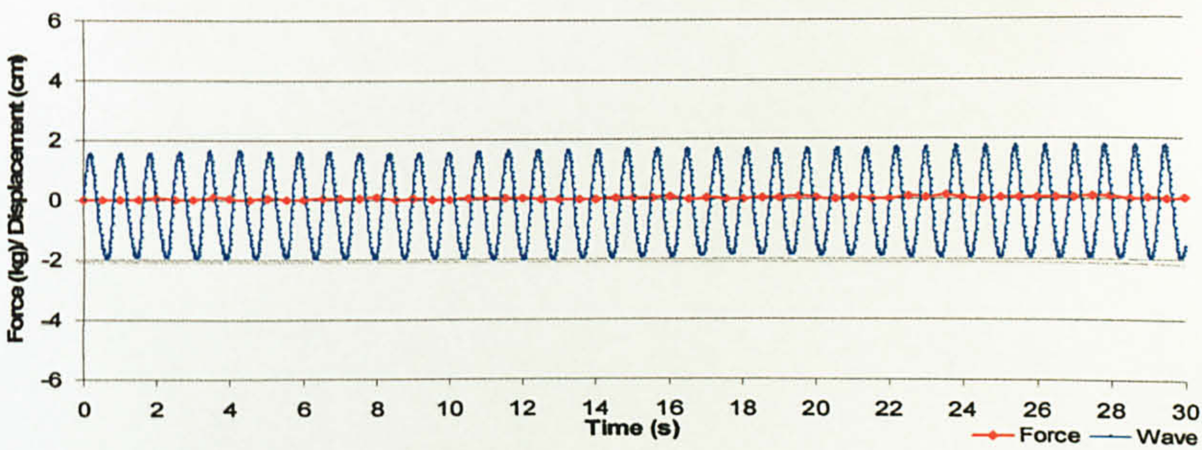

Figure 52c: Force Test Run 6

Figure 52 Force Test 2

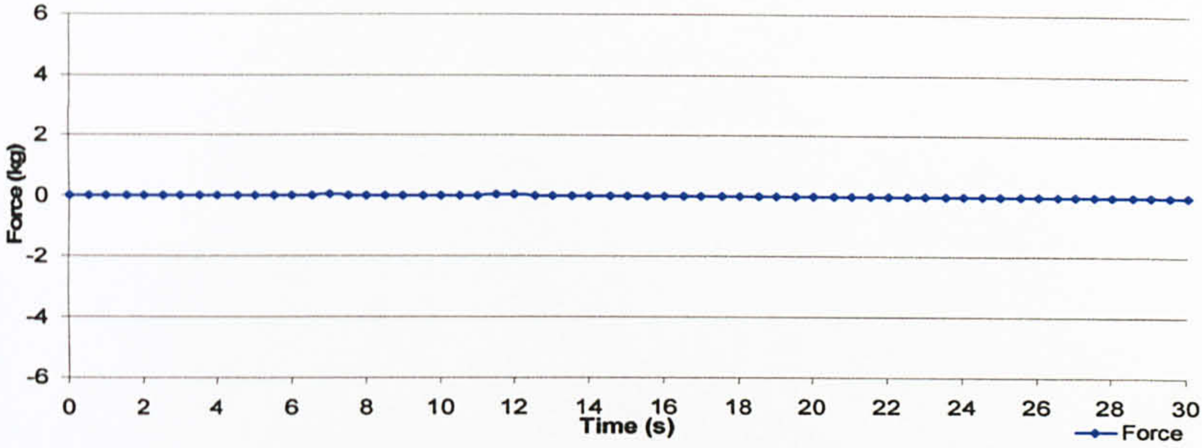

Figure 53a: Force Test Run 7

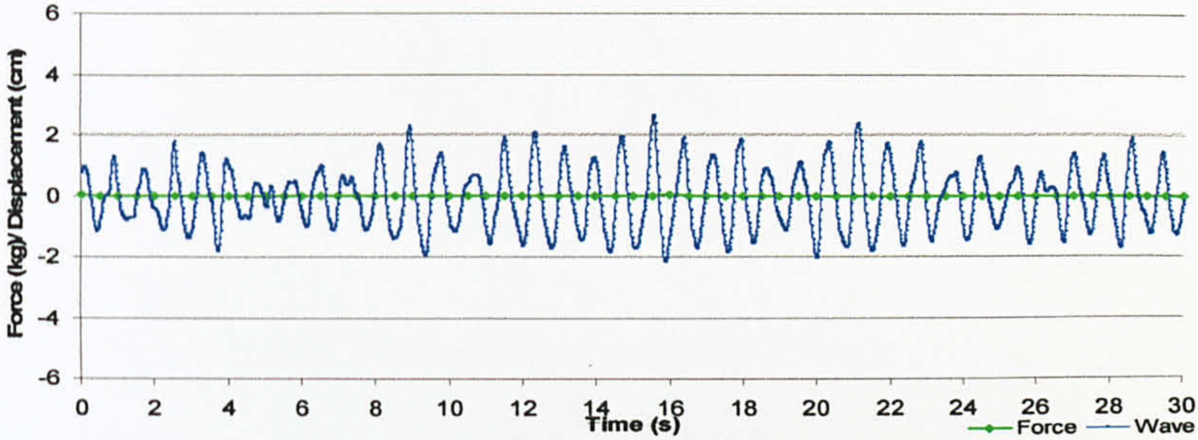

Figure 53b: Force Test Run 8

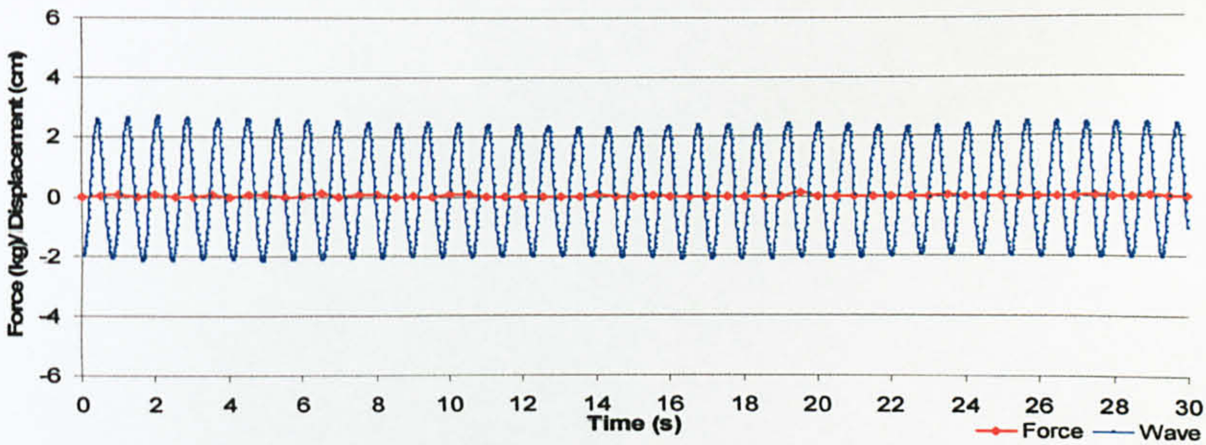

Figure 53c: Force Test Run 9

Figure 53 Force Test 3

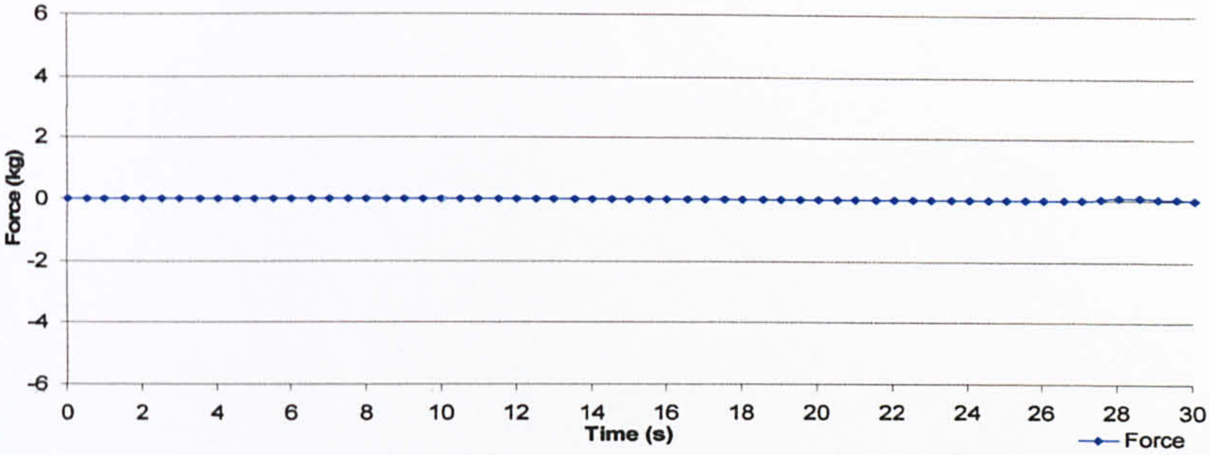

Figure 54a: Force Test Run 10

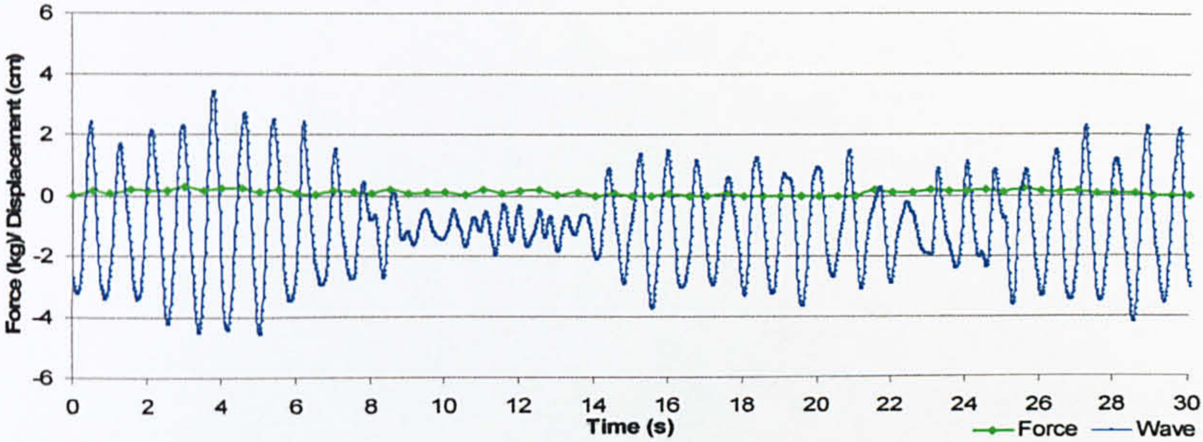

Figure 54b: Force Test Run 11

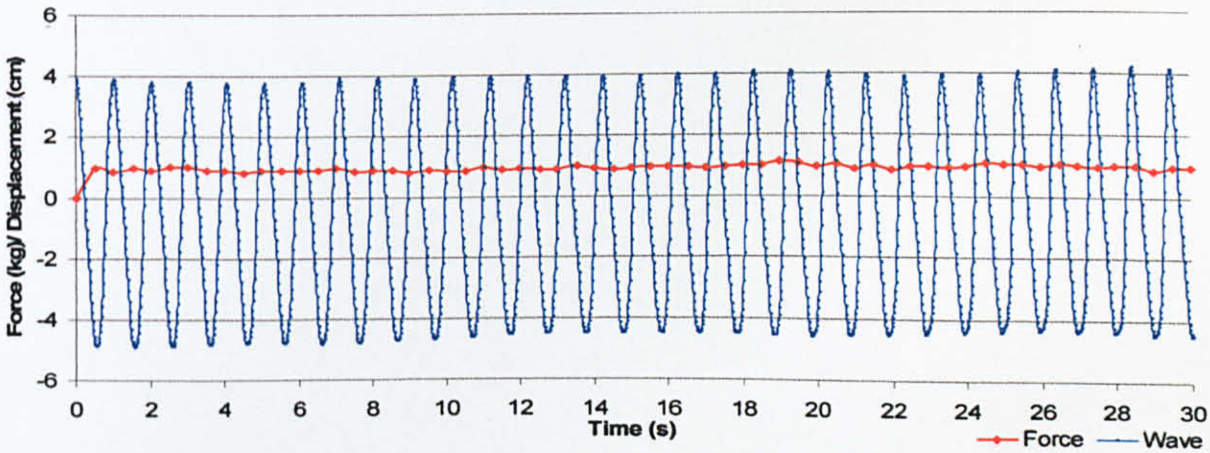

Figure 54c: Force Test Run 12

Figure 54 Force Test 4

CHAPTER 5
CONCLUSSIONS

The semi–submersible offshore platform for Malaysian waters was scale modelled and a series of laboratory tests under regular and random wave action was conducted. The model is a semi–submersible with a hollow square pontoon and four columns, has a hull width of 83 cm, total hull height of 37.4 cm, total height of 49 cm, topside width of 65 cm, total mass of 54.6 kg with full ballast and 36.6 kg with minimum ballast. The semi–submersible is moored by 16 symmetric mooring lines anchored to the basin floor. The experiments were conducted in a basin of 20 m×10m. Wave heights of 3-15 cm with wave periods 0.8 sec were tried with two different loading conditions: maximum loading and minimum loading, and also under two different mooring positions.

Three of the tests with regular waves and one of the tests with random waves were chosen for detailed analysis of the results. The analysis gave the following conclusions:

- The scale model performed quite satisfactory and the simulated results show a good overall resemblance to the prototype *(real-life)* structure.
- Waves with larger wave periods lead to larger surge, heave and pitch responses of the semi–submersible.
- The condition of full ballast, corresponding to heavier structure resulting from larger oil storage, is associated with larger responses in terms of heave, surge and pitch.
- From the tests analysed, the maximum heave displacement was under 18.8%, the maximum surge displacement was under 5.8%, and the maximum pitch was less than 11.6°.

- There will be difference in the result of computer analysis and experimental study, because the response will be influence by the wave scaled down for each analysis.
- The semi–submersible did not respond differently due to the type of waves, it will only be influenced by wave height and wave period.

This experimental study had also produced an equation of motion that can be use to predict the heave motions of a semi–submersible platform due to waves. The EOM is $52.6x'' + 130.73x' + 90x = 0$.

A force test was also conducted to obtain the values of wave and current forces towards the semi-submersible model. The result from this test will allow other people to do comparison of force calculation theoretically with the experimental values. One of the comparisons could be the Froude-Krylov theory of wave force calculation.

CHAPTER 6
ECONOMIC BENEFITS

6.1 Project Cost

The semi–submersible offshore platform for Malaysian waters was scale modelled for a series of laboratory tests. The model is a semi–submersible with a hollow square pontoon and four columns, has a hull width of 83 cm, total hull height of 37.4 cm, total height of 49 cm, and topside width of 65 cm. The semi–submersible model is moored by 16 symmetric mooring lines anchored to the basin floor. Figure 7 from Chapter 3, shows a picture of the scale model with label on each component material. Total cost to construct the whole model is in Table 9 below.

Table 9 Project Cost

No	Component	Price (RM)
1	Column + Pontoon (Perspex)	880
2	Topside (Wood)	-
3	Steel Plate	-
4	Rubber Mat	30
5	Mooring (Fishing Line)	20
6	Miscellaneous	100
Total		1030

The most expensive part about this research is to construct the model. The model would cost more depending on the material used. Even if it is using the same Perspex material, different fabricators would quote the price differently. So the cheapest price obtained to fabricate the model was RM880. The topside was actually taken from a previous similar model and the steel plates were taken from the Concrete Laboratory leftovers. So the total for the whole fabrication of the semi-submersible model was RM1030. It is somehow expensive, but in the long run, the model can be used over and over again and it will save others, as they do not have to build a new model if they continue on with this research.

6.2 Economic Benefits

Nowadays, oil and gas companies are always searching ways to cut down their costs and gaining more profit. With the oil are now more located in deep water operations, the costs will surely increase instead of decrease. So oil companies will do a lot of research and development to cut down their cost of construction and operation. One of the researches is also doing scale model testing. There are certain oil and gas consultants that are conducting scale model testing for new offshore platforms for example for the new dry-tree semi-submersibles. From this sort of research, oil companies can gain input on how to design their new platforms. With a well refined design, it can save on the construction days, or material or the platform aspects and from there could have actually save millions of dollars. From this research also, oil companies can predict the movements of the new platform so they can know how to operate the platform much better, thus saving a lot of money on operating the platform. So from the scale model test results, oil companies or researchers can use its data, so that it may help in the design of a semi-submersible platform in the future and it can reduce its cost. For example, PETRONAS themselves can use this data in the future to design a good semi-submersible platform and with that decreasing its construction and maintenance cost.

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APPENDIX

Hydrostatic Stability of Semi-Sub Model

Maximum Loading

Draft = 85 ft
= 26 m

Scale is 1:100

Scaled down draft = 26/100
= 0.26 m
= 26 cm
≈ 30 cm

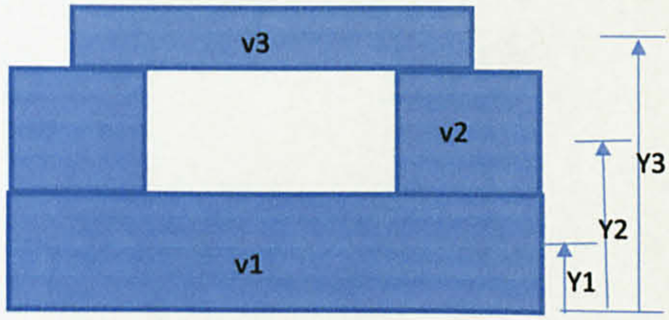
Model Weight
Pontoon = 30.89 kg
Column = 5.31 kg
Topside = 18.25 kg

Height
Y1 = 0.065 m
Y2 = 0.252 m
Y3 = 0.4265 m

Dimensions

	No.	Height (m)	Length (m)	Width (m)
Pontoon (outer)	1	0.13	0.83	0.83
Pontoon (Inner)	1	0.13	0.53	0.53
Column	4	0.244	0.15	0.15
Topside	1	0.105	0.68	0.68

Volume
Pontoon = 0.05304 m^3
Column = 0.02196 m^3
Topside = 0.048552 m^3



Center of Gravity (COG)

COG = $\sum WY / \sum W$
= 0.204 m
= 20.442 cm

Center of Buoyancy (COB)

COB = $\sum VY / \sum V$
= 0.240 m
= 24.030 cm

GB = COB - COG
= **3.587 cm**

MB = I / Vs

where, I is the Moment of Inertia of the water plane area
Vs is the volume of displaced water

I = $Ixx + (A \times d^2)$

Area at the water plane only include column area
so,
Area, A = 0.0225 m^2

d is the distance between center of column to the mid length of the hull
so,
d = 34 cm
d^2 = 1156 cm
= 0.1156 m

Ixx = $bd^3/12$ b 0.15
= 4.219E-05 m^4 d 0.15

so, I = $Ixx + (A \times d^2)$
= 0.0026432 m^4

Draft = 30 cm
= 0.3 m

Vs = 0.027 m^3

MB = I / Vs
= 0.10 m
= **9.79 cm**

MG = MB - GB
= **6.202 cm**

MG is >1 so, this mean the model can float stable in water

Hydrostatic Stability of Semi-Sub Model

Minimum Loading

Draft = 19.4 ft
= 5.91 m

Scale is 1:100

Scaled down draft = 6/100
= 0.06 m
= 5.91 cm
≈ 6 cm

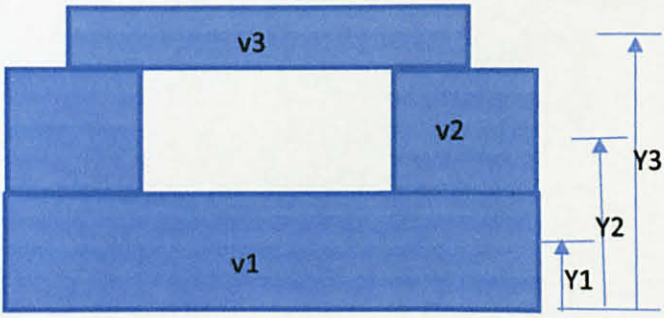
Model Weight
Pontoon = 30.89 kg
Column = 5.31 kg
Topside = 0.00 kg

Height
Y1 = 0.065 m
Y2 = 0.252 m
Y3 = 0.4265 m

Dimensions

	No.	Height (m)	Length (m)	Width (m)
Pontoon (outer)	1	0.13	0.83	0.83
Pontoon (Inner)	1	0.13	0.53	0.53
Column	4	0.244	0.15	0.15
Topside	1	0.105	0.68	0.68

Volume
Pontoon = 0.05304 m^3
Column = 0.02196 m^3
Topside = 0.048552 m^3



COG	=	∑WY/∑W
	=	0.092 m
	=	9.241 cm

<u>Center of Buoyancy (COB)</u>

COB	=	∑VY/∑V
	=	0.240 m
	=	24.030 cm
GB	=	COB - COG
	=	**14.789 cm**
MB	=	I / Vs

where, I is the Moment of Inertia of the water plane area
Vs is the volume of displaced water

			Bo	0.83
I	=	$(BoHo^3/12) - (BiHi^3/12)$	Ho	0.83
	=	0.0329732 m^4	Bi	0.53
			Hi	0.53
Draft	=	6.00 cm		
	=	0.06 m		
Vs	=	0.02448 m^3		
MB	=	I / Vs		
	=	1.3469444 m		
	=	**134.69444 cm**		
MG	=	MB - GB		
	=	**119.906 cm**		

<u>MG is >1 so, this mean the model can float stable in water</u>

Draft comparison with Weight

Tow out/ Loading

Draft (ft)	19.4
pontoon height (ft)	40

so, only half of the pontoon is submerged

Pontoon submerged (ft) 20.6 ~ 21ft

Volume pontoon submerged (270 X 270 X 21) - (160 X 160 X 21)
= 993300 ft^3
= 28127 m^3

take density of seawater as 1030 kg/m^3

Weight of submerged platform 1030 X 28127
= 28970810 kg
= 63874 Kips

Operating

Draft (ft)	85
pontoon height (ft)	40
column height (ft)	80

so, the whole pontoon have been submerged and only half of pontoon submerged

Column submerged (ft) 45

Volume column submerged 50 X 50 X 45
= 112500 ft^3
= 3186 m^3

Volume of pontoon 1892000 ft^3
53575 m^3

take density of seawater as 1030 kg/m^3

Weigh of submerged column 1030 X 3186
= 3281580 kg
= 7235 Kips

Weight of submerged platform 55182250 kg
121665 Kips

Total weight 58463830 kg
128900 Kips

Survival

Draft (ft)	66.8
pontoon height (ft)	40

column height (ft)	80

so, the whole pontoon have been submerged and only half of pontoon submerged

Column submerged (ft)	26.8 ~ 27ft
Volume column submerged	50 X 50 X 27
	= 67500 ft^3
	= 1911 m^3
Volume of pontoon	1892000 ft^3
	53575 m^3

take density of seawater as 1030 kg/m^3

Weigh of submerged column	1030 X 1911
	= 1968330 kg
	= 4340 Kips
Weight of submerged platform	55182250 kg
	121665 Kips
Total weight	57150580 kg
	126004 Kips

eight calculation

ale 1:100

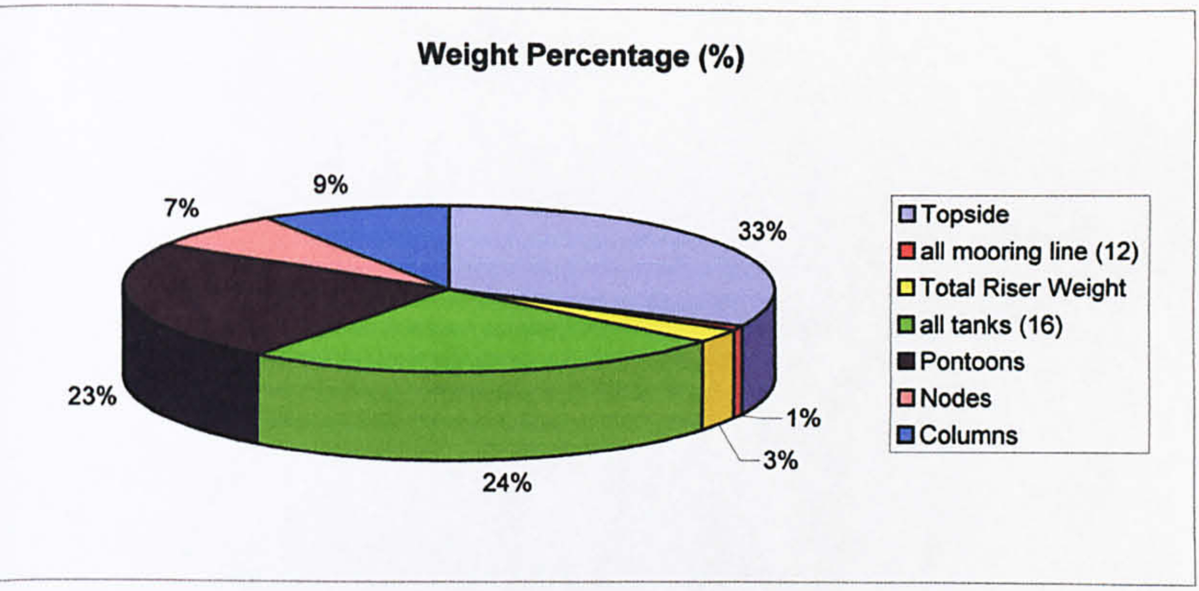
tal weight given in the report (kips) 124,436

scription	Weight (Kips)	Weight (kN)	Percentage (%)	Model Weight (Kg)	Model Weight (grams)
pside	40256	179068	32.4	18.254	18253.54
mooring line (12)	816	3630	0.7	0.370	370.00
tal Riser Weight	3550	15791	2.9	1.610	1609.70
tanks (16)	29920	133091	24.0	13.567	13566.82
ntoons	29094	129417	23.4	13.192	13192.28
des	9100	40479	7.3	4.126	4126.27
lumns	11700	52044	9.4	5.305	5305.21
tal weight check	124436	553518	100.0	56.4	56423.8

ight in (kN) convert to Kg 56423823 kg

aled down total W = 56423823/(100^3)
= 56.4 kg

the total model weight (kg) 56.4
al hull weight (without tanks) (kg) 22.624
al hull weight (with tanks) (kg) 36.191



Weight calculation

Scale 1:100

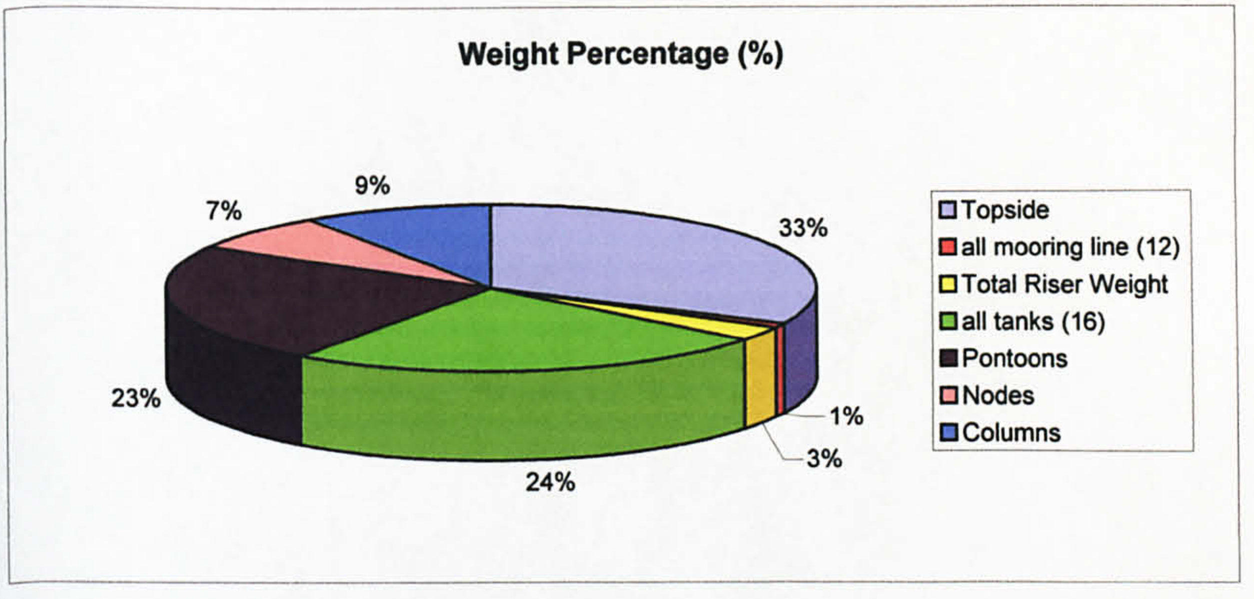
Total weight given in the report (kips) 124,436

Description	Weight (Kips)	Weight (kN)	Percentage (%)	Model Weight (Kg)	Model Weight (grams)
Topside	40256	179068	32.4	18.254	18253.54
all mooring line (12)	816	3630	0.7	0.370	370.00
Total Riser Weight	3550	15791	2.9	1.610	1609.70
all tanks (16)	29920	133091	24.0	13.567	13566.82
Pontoons	29094	129417	23.4	13.192	13192.28
Nodes	9100	40479	7.3	4.126	4126.27
Columns	11700	52044	9.4	5.305	5305.21
Total weight check	124436	553518	100.0	56.4	56423.8

weight in (kN) convert to Kg 56423823 kg

scaled down total W = 56423823/(100^3)
= 56.4 kg

so, the total model weight (kg) 56.4
total hull weight (without tanks) (kg) 22.624
total hull weight (with tanks) (kg) 36.191



Calculate thickness respective to material density

Pontoon Dimensions

Height (cm)	13	Perspek density	1.19
Length (cm)	68	Steel plate densit	7.85
Width (cm)	15		

Material	Material Density	Weight (kg)	No.	Surface Area (m^2)	Thickness (mm)	Description
Perspek	1.19	17.32	4	0.3808	9.55	without tanks
Perspek	1.19	30.89	4	0.3808	17.04	with tanks
Steel plate	7.85	17.32	4	0.3808	1.45	without tanks
Steel plate	7.85	30.89	4	0.3808	2.58	with tanks

Column Dimensions (square)

Height (cm)	24.4	Perspek density	1.19
Length (cm)	15	Steel plate densit	7.85
width (cm)	15		

Material	Material Density	Weight (kg)	No.	Surface Area (m^2)	Thickness (mm)
Perspek	1.19	5.31	4	0.1914	5.82
Steel plate	7.85	5.31	4	0.1914	0.88

Column Dimension (cylinder)

Diameter (cm)	20	Perspek density	1.19
Perimeter (cm)	63	Steel plate densit	7.85
Height (cm)	24.4		

Material	Material Density	Weight (kg)	No.	Surface Area	Thickness (mm)
Perspek	1.19	5.31	4	0.2161	5.16
Steel plate	7.85	5.31	4	0.2161	0.78

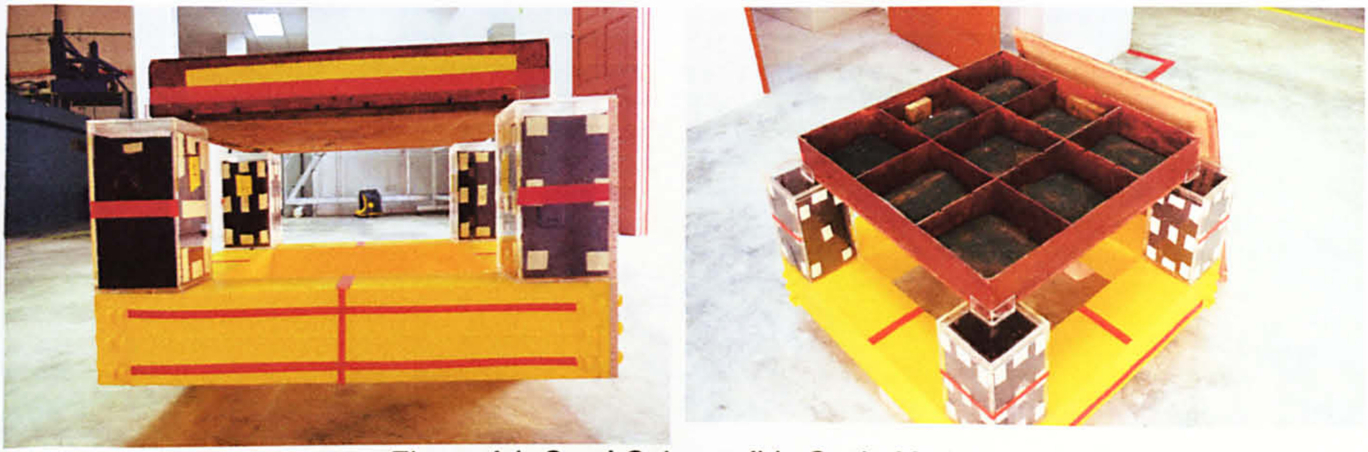


Figure A1: Semi-Submersible Scale Model

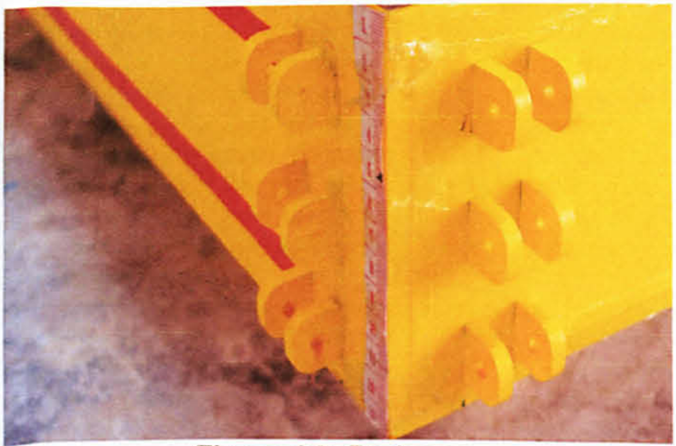


Figure A2: Padeyes

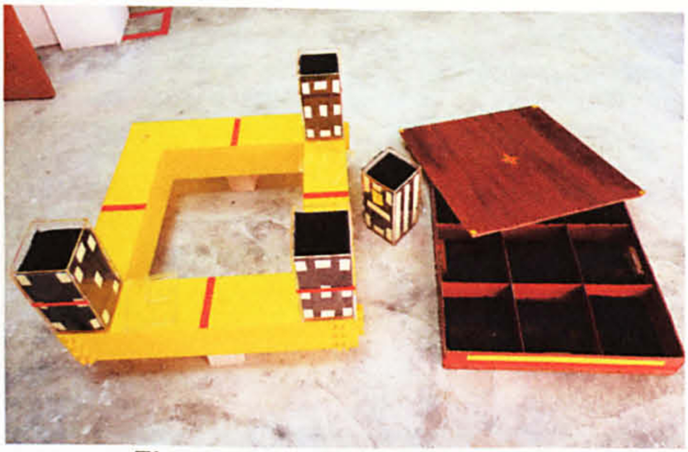


Figure A3: Model Components

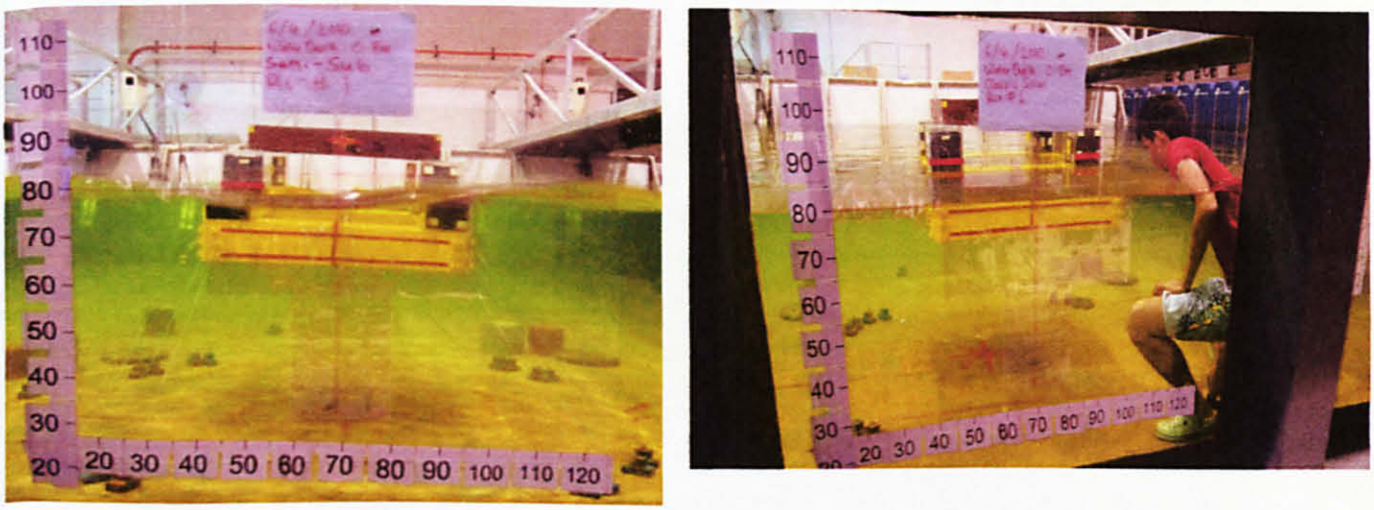


Figure A4: Model in Wave Basin

Figure A: Picture of Semi – Submersible Model

Test 4 Results

Time	Surge (cm)	Heave (cm)	Pitch (°)
0.0	0.00	0.00	-1.46
0.5	-0.94	-1.88	-1.46
1.0	0.00	-2.82	-4.36
1.5	-0.94	0.00	-1.46
2.0	-0.94	0.00	2.91
2.5	0.00	-2.82	-4.36
3.0	0.00	0.00	-2.91
3.5	-0.94	0.00	4.36
4.0	0.00	-3.76	-4.36
4.5	-1.88	0.00	-2.91
5.0	-0.94	0.00	1.46
5.5	0.00	-2.82	-4.36
6.0	0.00	0.00	1.46
6.5	-0.94	0.00	0.00
7.0	-0.94	-2.82	-2.91
7.5	-1.88	-0.94	-2.91
8.0	-0.94	0.00	0.00
8.5	-0.94	-0.94	0.00
9.0	0.00	-0.94	-1.46
9.5	0.00	0.00	-2.91
10.0	-0.94	0.00	4.36
10.5	-0.94	-1.88	-2.91
11.0	-1.88	0.00	-2.91
11.5	-0.94	0.00	1.46
12.0	0.00	-2.82	-5.80
12.5	-0.94	0.00	0.00
13.0	-0.94	0.94	1.46
13.5	0.00	-2.82	-4.36
14.0	-1.88	0.00	0.00
14.5	-0.94	0.94	1.46
15.0	0.00	-1.88	-2.91
15.5	-0.94	0.00	0.00
16.0	0.00	0.00	-1.46
16.5	-0.94	-1.88	-1.46
17.0	0.00	-2.82	-4.36
17.5	-0.94	0.00	-1.46
18.0	-0.94	0.00	1.46
18.5	0.00	-1.88	-2.91
19.0	-0.94	0.00	0.00
19.5	-1.88	0.94	1.46
20.0	0.00	-1.88	-4.36
20.5	-1.88	0.00	2.91
21.0	-0.94	0.00	0.00
21.5	0.00	-1.88	-2.91
22.0	-1.88	0.00	4.36
22.5	-0.94	0.00	-1.46
23.0	-0.94	-0.94	-4.36
23.5	-1.88	0.94	4.36
24.0	-0.94	-3.76	-4.36
24.5	-1.88	0.94	-1.46
25.0	-0.94	-0.94	-1.46
25.5	-0.94	0.00	-1.46
26.0	-0.94	0.94	1.46
26.5	0.00	0.00	0.00
27.0	-0.94	0.00	0.00
27.5	-0.94	0.00	-1.46
28.0	0.00	0.94	0.00
28.5	-0.94	0.00	1.46
29.0	0.00	-0.94	-4.36
29.5	-0.94	0.94	0.00
30.0	-0.94	0.00	2.91

Test 16 Results

Time	Surge (cm)	Heave (cm)	Pitch (°)
0.0	0.00	0.00	0.00
0.5	-0.94	0.00	-1.46
1.0	-0.94	0.00	0.00
1.5	0.00	0.00	0.00
2.0	-0.94	-0.94	-2.91
2.5	-0.94	0.00	0.00
3.0	0.00	0.00	-1.46
3.5	-0.94	-0.94	-2.91
4.0	0.00	0.00	0.00
4.5	-0.94	0.00	0.00
5.0	-0.94	0.00	0.00
5.5	0.00	0.00	0.00
6.0	-0.94	0.00	-1.46
6.5	0.00	0.00	0.00
7.0	0.00	0.00	-1.46
7.5	-0.94	-0.94	-2.91
8.0	0.00	0.00	0.00
8.5	-0.94	-0.94	-2.91
9.0	0.00	0.00	0.00
9.5	0.00	0.00	-1.46
10.0	-0.94	-0.94	-2.91
10.5	0.00	0.00	0.00
11.0	-0.94	0.00	-1.46
11.5	-0.94	-0.94	-2.91
12.0	0.00	0.00	0.00
12.5	-0.94	-0.94	-2.91
13.0	-0.94	0.00	0.00
13.5	0.00	0.00	0.00
14.0	-0.94	-0.94	-2.91
14.5	-0.94	0.00	0.00
15.0	-0.94	0.00	-1.46
15.5	-0.94	-0.94	-2.91
16.0	0.00	0.00	0.00
16.5	-0.94	0.00	-1.46
17.0	-0.94	0.00	0.00
17.5	0.00	0.00	0.00
18.0	-0.94	-0.94	-2.91
18.5	0.00	0.00	0.00
19.0	0.00	0.00	-1.46
19.5	-0.94	-0.94	-2.91
20.0	0.00	0.00	0.00
20.5	-0.94	-0.94	-2.91
21.0	-0.94	0.00	0.00
21.5	0.00	0.00	0.00
22.0	-0.94	-0.94	-2.91
22.5	0.00	0.00	0.00
23.0	0.00	0.00	-1.46
23.5	-0.94	-0.94	-2.91
24.0	0.00	0.00	0.00
24.5	-0.94	0.00	-1.46
25.0	-0.94	0.00	0.00
25.5	0.00	0.00	0.00
26.0	-0.94	-0.94	-2.91
26.5	0.00	0.00	0.00
27.0	0.00	0.00	-1.46
27.5	-0.94	-0.94	-2.91
28.0	0.00	0.00	0.00
28.5	-0.94	0.00	-1.46
29.0	-0.94	0.00	0.00
29.5	0.00	0.00	0.00
30.0	-0.94	-0.94	-2.91

Test 26 Results

Time	Surge (cm)	Heave (cm)	Pitch (°)
0.0	0.00	-0.94	-1.46
0.5	0.94	-4.70	-7.24
1.0	0.94	0.94	2.91
1.5	-0.94	-4.70	-8.67
2.0	0.94	-2.82	-4.36
2.5	-1.88	-1.88	-4.36
3.0	0.00	-4.70	-8.67
3.5	0.00	0.94	2.91
4.0	-1.88	-3.76	-7.24
4.5	0.94	-1.88	-2.91
5.0	-1.88	-0.94	-4.36
5.5	0.00	-4.70	-7.24
6.0	0.00	0.00	1.46
6.5	-2.82	-4.70	-8.67
7.0	0.00	-1.88	-4.36
7.5	-1.88	-2.82	-4.36
8.0	-0.94	-5.64	-7.24
8.5	0.00	0.94	1.46
9.0	-2.82	-5.64	-7.24
9.5	0.94	-1.88	-2.91
10.0	-1.88	-1.88	-2.91
10.5	0.00	-6.58	-5.80
11.0	0.00	1.88	1.46
11.5	-1.88	-5.64	-7.24
12.0	0.94	-2.82	-1.46
12.5	-0.94	-1.88	-4.36
13.0	0.00	-5.64	-7.24
13.5	0.00	1.88	2.91
14.0	-1.88	-5.64	-7.24
14.5	0.00	-1.88	-1.46
15.0	-2.82	-1.88	-4.36
15.5	0.00	-6.58	-7.24
16.0	0.00	1.88	1.46
16.5	-2.82	-5.64	-8.67
17.0	0.94	-2.82	-2.91
17.5	-1.88	-1.88	-4.36
18.0	0.00	-5.64	-5.80
18.5	0.00	2.82	2.91
19.0	-2.82	-5.64	-8.67
19.5	0.94	-0.94	0.00
20.0	-1.88	-0.94	-4.36
20.5	0.00	-5.64	-5.80
21.0	0.00	2.82	2.91
21.5	-1.88	-5.64	-7.24
22.0	0.94	-2.82	-2.91
22.5	-1.88	-2.82	-5.80
23.0	0.00	-6.58	-7.24
23.5	0.00	1.88	1.46
24.0	-2.82	-5.64	-8.67
24.5	0.94	-1.88	-1.46
25.0	-1.88	-0.94	-2.91
25.5	0.00	-5.64	-5.80
26.0	0.00	1.88	1.46
26.5	-1.88	-4.70	-5.80
27.0	0.94	-2.82	-1.46
27.5	-1.88	-1.88	-4.36
28.0	0.00	-5.64	-5.80
28.5	0.00	2.82	2.91
29.0	-2.82	-4.70	-7.24
29.5	0.94	-2.82	-2.91
30.0	0.00	-0.94	-1.46

Test 30 Results

Time	Surge (cm)	Heave (cm)	Pitch (°)
0.0	0.00	-0.94	-1.46
0.5	0.00	-0.94	-1.46
1.0	0.00	-0.94	-1.46
1.5	0.00	0.00	0.00
2.0	0.00	0.00	0.00
2.5	0.00	-1.88	-2.91
3.0	0.00	0.00	1.46
3.5	0.00	-0.94	-1.46
4.0	0.00	-1.88	-4.36
4.5	-0.94	-1.88	-2.91
5.0	-0.94	-2.82	-4.36
5.5	0.00	-0.94	-1.46
6.0	0.00	-1.88	-1.46
6.5	0.00	0.00	0.00
7.0	0.94	-1.88	-1.46
7.5	0.94	0.00	0.00
8.0	0.00	0.00	4.36
8.5	0.00	-1.88	-2.91
9.0	-0.94	0.00	0.00
9.5	-0.94	-2.82	-4.36
10.0	-0.94	-1.88	-2.91
10.5	-0.94	-1.88	-1.46
11.0	0.00	-3.76	-5.80
11.5	0.00	-1.88	0.00
12.0	0.00	-1.88	-1.46
12.5	0.00	-0.94	-1.46
13.0	0.94	0.00	0.00
13.5	0.94	0.00	0.00
14.0	0.00	0.00	0.00
14.5	0.94	0.00	0.00
15.0	0.00	-0.94	-1.46
15.5	0.00	-0.94	0.00
16.0	0.00	-1.88	-2.91
16.5	-0.94	-3.76	-5.80
17.0	-1.88	-2.82	-4.36
17.5	-0.94	-3.76	-5.80
18.0	0.00	-0.94	-1.46
18.5	0.00	0.00	1.46
19.0	0.94	0.00	0.00
19.5	1.88	0.00	0.00
20.0	0.94	-0.94	-1.46
20.5	0.00	-0.94	1.46
21.0	0.00	-2.82	-4.36
21.5	-0.94	-0.94	-1.46

Time	Surge (cm)	Heave (cm)	Pitch (°)
22.0	-1.88	-2.82	-4.36
22.5	-1.88	-3.76	-4.36
23.0	-0.94	-1.88	-2.91
23.5	0.00	-0.94	-2.91
24.0	0.00	-1.88	-1.46
24.5	0.94	-0.94	0.00
25.0	0.00	-0.94	-1.46
25.5	0.00	0.00	1.46
26.0	0.00	-1.88	-2.91
26.5	0.00	0.00	0.00
27.0	0.00	-1.88	-2.91
27.5	0.00	-0.94	-1.46
28.0	0.00	0.00	0.00
28.5	0.00	-1.88	-2.91
29.0	0.00	-0.94	-1.46
29.5	-0.94	-0.94	-1.46
30.0	-0.94	-1.88	-2.91
30.5	-0.94	-1.88	-1.46
31.0	-0.94	-1.88	-1.46
31.5	0.00	-1.88	0.00
32.0	0.00	-0.94	-1.46
32.5	0.94	-1.88	-1.46
33.0	0.00	-0.94	-1.46
33.5	0.00	-0.94	1.46
34.0	0.00	-1.88	-2.91
34.5	-0.94	0.00	0.00
35.0	-0.94	-1.88	-4.36
35.5	-0.94	-1.88	-2.91
36.0	-0.94	-2.82	-4.36
36.5	0.00	-1.88	-4.36
37.0	0.00	-1.88	1.46
37.5	0.00	-2.82	-2.91
38.0	0.00	-1.88	-1.46
38.5	0.00	-1.88	-2.91
39.0	0.00	-1.88	-2.91
39.5	0.00	0.00	0.00
40.0	0.00	-0.94	-1.46
40.5	0.00	0.00	0.00
41.0	0.94	0.00	0.00
41.5	0.94	-0.94	-1.46
42.0	0.94	0.00	0.00
42.5	0.00	-1.88	-1.46
43.0	0.00	-1.88	-2.91
43.5	-0.94	-3.76	-5.80

Test 30 Results (Continued)

Time	Surge (cm)	Heave (cm)	Pitch (°)
44.0	-0.94	-2.82	-2.91
44.5	-0.94	-1.88	-2.91
45.0	0.00	-0.94	0.00
45.5	0.00	-0.94	-1.46
46.0	0.94	0.00	0.00
46.5	0.94	-0.94	-1.46
47.0	0.00	0.00	1.46
47.5	0.00	-2.82	-4.36
48.0	-0.94	-0.94	-1.46
48.5	-0.94	-1.88	-2.91
49.0	-0.94	-3.76	-7.24
49.5	0.00	-1.88	-2.91
50.0	0.00	-1.88	-1.46
50.5	0.00	-0.94	-1.46
51.0	0.00	-1.88	-1.46
51.5	0.00	-0.94	-1.46
52.0	0.00	0.00	1.46
52.5	0.00	-0.94	-1.46
53.0	0.00	0.00	0.00
53.5	0.00	0.00	0.00
54.0	0.94	-0.94	-1.46
54.5	0.94	0.00	0.00
55.0	0.00	-1.88	-1.46
55.5	-0.94	-1.88	-2.91
56.0	-1.88	-2.82	-4.36
56.5	-0.94	-2.82	-4.36
57.0	0.00	-0.94	-1.46
57.5	0.00	-0.94	0.00
58.0	0.00	0.00	0.00
58.5	0.94	0.00	0.00
59.0	0.94	-1.88	-2.91
59.5	0.94	0.00	2.91
60.0	0.00	-2.82	-4.36